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# R and D CENTER LABORATORY TECHNICAL REPORT

NO. 13091

DEVELOPMENT OF A HIGH STRENGTH

ISOTHERMALLY HEAT-TREATED NODULAR IRON

ROAD WHEEL ARM

CONTRACT No DAAE07-83-C-R051

U.S. ARMY TACOM


by

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)


This contract was awarded to investigate the use of isothermally heat-treated nodular iron as a material for tank road wheel arms. The aim is to make a unit that is appropriate to the application while weighing significantly less and is less costly. Design considerations are discussed and the material characterized. Both static and dynamic tests are performed. The stress analysis is documented.


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## PREFACE

This final report covers work done under Contract No DAAE07-83-C-R051, titled " Development of a High Strength Isothermally Heat-Treated Nodular Iron Road Wheel Arm." The report spans March 1983 through March 1985.

The contract was awarded to Hayes-Albion by the US Army Tank Auto-motive Command (TACOM). It was carried out under the technical direction of Michael Holly and later Avery H.Fisher, TACOM, Warren MI.

The project activities were under the technical guidance of A.R. Moore, experimental engineer. Hayes-Albion. The project was under the general direction of James Paternoster, technical director, Hayes-Albion Corp.,Albion Division. Stress analysis and testing was under the direction of Lary Geer, corporate special projects engineer, Hayes-Albion Corp. Other areas of assistance were given by James Falconer, manager, tool engineering, Hayes-Albion and Nick Januszewski, sales engineer, Hayes-Albion Corp.

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## 1.0. INTRODUCTION

This final report was prepared by Hayes-Albion Corp. for the US Army Tank-Automotive Command under Contract No DAAE07-83-C-R051. It describes the redesign, material characterization, material selection, manufacture, and testing of a proposed road wheel arm for the M1 tank. The material selected is bainitic ductile iron (BDI). This material made by the casting process and heat-treatment, takes advantage of the toughness of bainite (acicular ferrite), the ability of the casting process to make a complex shape, and a 10 percent lighter than steel weight. A further advantage is its relatively low cost compared to a steel forging. The part is shown in Fig. 1-1.

## 2.0. OBJECTIVE

The main objective of the project was to supply a road wheel arm of equal or better performance than the existing one, with a weight and cost reduction. A secondary objective was to conduct an investigation into BDI to characterize its properties over a broad range.

## 3.0. CONCLUSIONS

A set of 14 road wheel arms were made and assembled. Dynamic tests on the design passed the 650,000 cycle specification, going beyond one million cycles. A 35 pound or 27 percent weight savings per arm was achieved, and based on figures obtained during the project, a considerable cost reduction can be effected.

Data were generated during the investigation and characterization phase to allow design calculations to be made with more confidence.

## 4.0. RECOMMENDATIONS

### 4.1. <u>Design</u>

Figures obtained during the static and dynamic tests indicate that further refinement of the design should be done. This involves a redistribution of metal from areas of low stress to areas of high stress. Such a change would not affect the overall weight but would increase the safety factor.

4.1.1. Material Characterization. The material was characterized using one austenitizing temperature ($1650^{\circ}F$) throughout, varying the quench temperatures and times. Investigation should be made

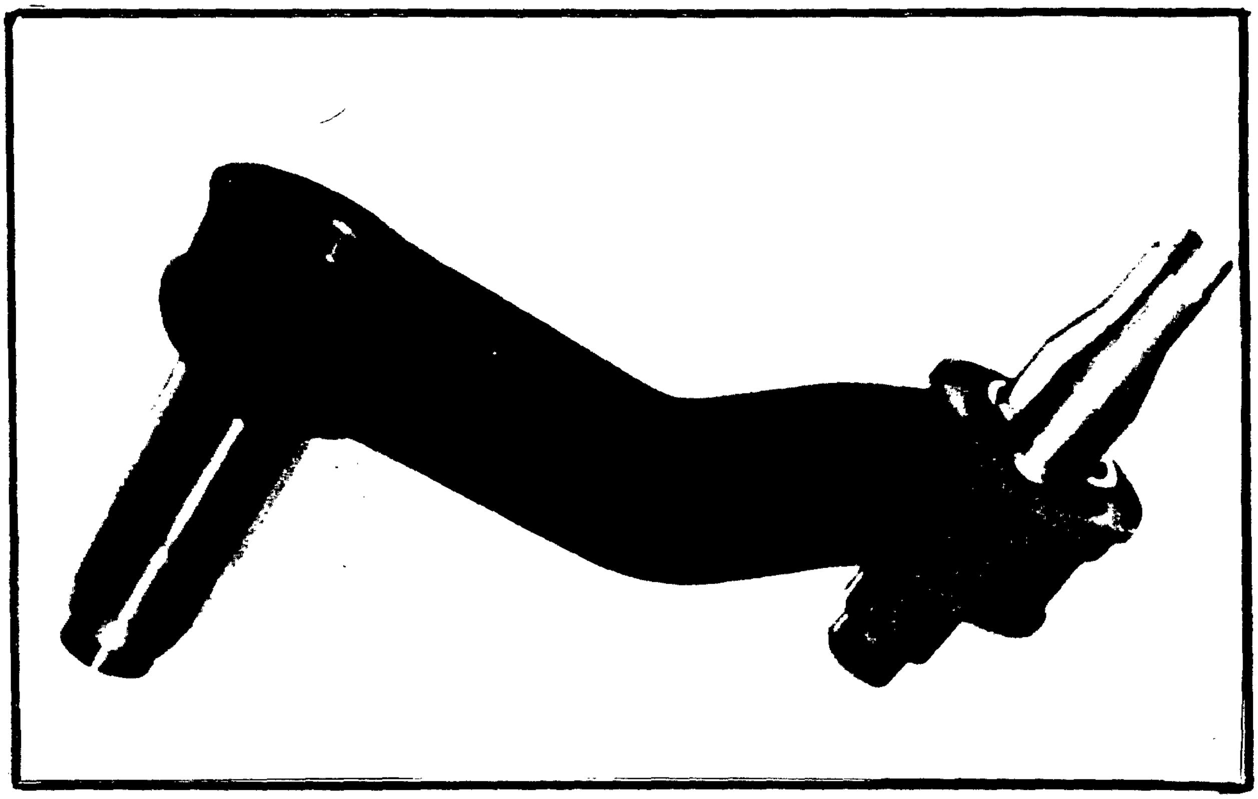


Fig 1-1. Isothermally Heat-Treated Nodular Iron Road Wheel Arm.

into varying the austenitizing temperatures as information on this comes to light.

4.1.2. Control. In the course of the investigation and testing, it was demonstrated that isothermally heat-treated nodular iron is quite notch sensitive. Every effort must be made to avoid grinding gouges on the outside of the casting. Likewise,no holes should be drilled in the casting for any reason. The manufacture of BDI is time-temperature-chemistry sensitive. Control must be close over these variables. Vendors bidding on future requirements should show that they routinely control their product metallurgically and that they can produce BDI to specification.

## 4.2. Further Recommendations

Castings made for this project had a ladle addition of Molybdenum (see Table 4-1a). It would be advantageous to further characterize the material through varying key elements such as carbon, silicon, copper, manganese, and molybdenum. An important field of study has been shown by the present project: the cause of notch sensitivity should be found and if possible methods of preventing it should be provided.

Two spacers on the assembly are presently made from forgings. These could be made from pearlitic ductile iron at much lower cost.

# 5.0. DISCUSSION

## 5.1. Background

Nodular or ductile iron is a readily available material whose manufacture is well understood by many foundries. In the as-cast condition, unalloyed nodular iron is made to several specifications (see Table 5-1). Alloyed primarily with copper, nickel, and molybdenum, it can be tailored to many specific applications in the normal to high temperature ranges. Unfortunately, it shares to a greater degree than specialty steels the tendency to lose strength at low temperatures. Isothermal heat-treatment not only improves the as-cast mechanical properties but significantly improves them at low temperatures to where they can compete with cryogenic steels.

5.1.1. Hayes-Albion made an unsolicited proposal to TACOM suggesting that BDI be investigated as a material suitable for tank road wheel arms. Mentioned in the proposal were the potential mechanical properties which could be in excess of 200,000 p.s.i. tensile strength, 180,000 p.s.i. yield strength and 10 percent elongation. These properties could be adjusted in the heat-treatment to produce optimum conditions for the application. Advantages cited were ease of manufacture, cost and weight reduction.

Table 4-1a. Chemistry of Contracted 14 Road Wheel Arms.

| C | SI | MN | S | MG | CR | CU | CE | AL | SN | P | MO | NL | TI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3.76 | 2.38 | 0.33 | 0.008 | N/A | 0.042 | 0.16 | 0.001 | 0.0103 | 0.015 | 0.336 | 0.2602 | 0.019 | 0.0269 |

Table 4-1b. Chemistry of Metal Poured in Characterization Test Bars.

| C | SI | MN | S | MG | CR | CU | CE | AL | SN | P | MO | NL | TI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3.76 | 2.29 | 0.3 | 0.011 | N/A | 0.052 | 0.10 | 0 | 0.0043 | 0.01 | 0.253 | 0.0079 | 0.013 | 0.019 |

Table 4-1c. Chemistry of Second Static Test Casting.

| C | SI | MN | S | MG | CR | CU | CE | AL | SN | P | MO | NL | TI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3.7 | 2.32 | 0.35 | 0.009 | N/A | 0.058 | 0.17 | 0 | 0.0119 | 0.015 | 0.0257 | 0.4354 | 0.026 | 0.0217 |

Table 4-1d. Chemistry of Third static and Second Dynamic Test Specimen.

| C | SI | MN | S | MG | CR | CU | CE | AL | SN | P | MO | NL | TI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3.79 | 2.45 | 0.34 | 0.011 | N/A | 0.052 | 0.19 | 0.002 | 0.007 | 0.014 | 0.0237 | 0.2596 | 0.034 | 0.0173 |

Table 4-1e Chemistry of High Molybdenum Test bars.

| C | SI | MN | S | MG | CR | CU | CE | AL | SN | P | MO | NL | TI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3.71 | 2.42 | 0.30 | 0.007 | N/A | 0.059 | 0.10 | 0.002 | 0.0106 | 0.014 | 0.0365 | 0.437 | 0.0253 | 0.0203 |

Table 5-1. Commercial Designations of Nodular Iron and Their Mechanical Properties.

| Commercial Name | Tensile p.s.i. | Yield p.s.i. | Elongation percent |
|---|---|---|---|
| D4018 | 60,000 | 40,000 | 18 |
| D4512 | 65,000 | 45,000 | 12 |
| D5506 | 80,000 | 55,000 | 6 |
| D7003 | 100,000 | 70,000 | 3 |
| D9002 | 120,000 | 90,000 | 2 |

## 5.2. Rationale

Using BDI for a tank road wheel arm is a good application for the following reasons:

- o The material is readily available.
- o The material is less energy intensive than a forging.
- o The product is a critical member and, as a casting, would be in a lower energy state than a forging.
- o The material weighs approximately 10 percent less than steel.
- o through the casting process, the part can be redesigned to increase the section modulus, put material where it is needed, and by design, reduce weight.

## 5.3. Design

Design of the original road wheel arm was done by General Dynamics Corporation. It was designed in 4150H or 4340H forged steel hardened to Rc 35-39. The part is simply two hubs joined by an oval sectioned offset arm (see Fig 5-1). In redesigning the part in BDI, it was specified that the plan and elevation envelopes were not to be exceeded. No stress values were available. All that could be obtained was the weight of the vehicle at 60 tons. Using this dead weight , we then examined three possibilities:

- o The existing oval section.
- o An "I" beam section.
- o A box section.

These sections were surveyed in a comparative manner and the results shown in tables 5-2 and 5-3. APPENDIX A1 through A 16 contains the details on these calculations. For comparison reasons the stresses were calculated under the following assumptions: (1) A beam of constant cross-section 20 ins. long. (2) For bending stress about the X axis a 20,000 pound verticle load was used. (3) For bending about the Y axis a 5,000 pound load was used. (4) The shear stress calculations were performed using a pure torque of 245,000 in. pounds. These stresses are for cross-section comparison on only. This method was utilised based on the limited load and restraint information provided). These values are not to be construed to be actual infield values. In Table 5-2 the existing section is first considered. The offset in the arm results in a torque being present as well as a bending moment. We must design particularly and with emphasis for

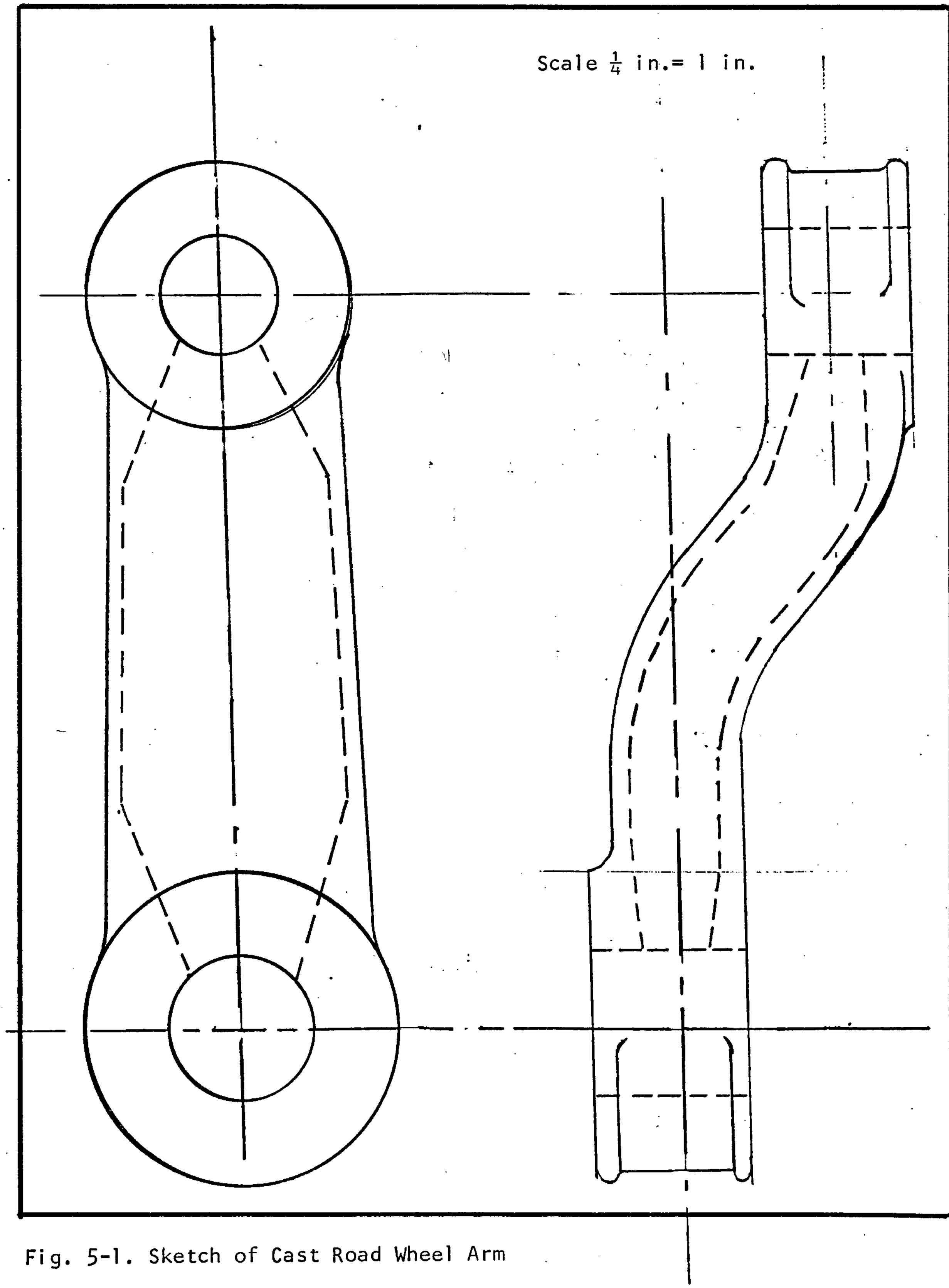



Fig. 5-1. Sketch of Cast Road Wheel Arm

5-2 Comparative Section Analysis and Corresponding Stresses of Arm Cross-Sections. in Simple Bending.

| Cross-Section Design | Area | $I_x$ | $I_y$ | J Polar Moment | Wt. lbs per in. Section | $\frac{A}{J}$ | $\sigma_x$ p.s.i. | $\sigma_y$ p.s.i. |
|---|---|---|---|---|---|---|---|---|
| APPENDIX A3 Existing Oval Section | 17.78 | 50.35 | 12.15 | 62.49 | 4.62 | 0.284 | 25,319 | 14,403 |
| APPENDIX A4 I Beam Sect. | 9.341 | 53.53 | 5.97 | 59.5 | 2.42 | 0.157 | 24,285 | 29,313 |
| APPENDIX A5 | 11.75 | 65.43 | 9.07 | 74.5 | 3.06 | 0.157 | 19,868 | 19,294 |
| APPENDIX A6 | 13.0 | 60.78 | 7.17 | 68.0 | 3.38 | 0.191 | 21,388 | 24,407 |
| APPENDIX A7 | 13.125 | 70.27 | 10.84 | 81.11 | 3.41 | 0.162 | 18,500 | 16,143 |
| APPENDIX A8 | 15.75 | 72.95 | 11.70 | 84.65 | 4.10 | 0.186 | 17,820 | 14,957 |
| APPENDIX A9 | 13.125 | 70.27 | 14.81 | 85.08 | 3.41 | 0.154 | 18,500 | 11,816 |
| APPENDIX A10 Box Section 9/16 in. Wall | 9.98 | 49.37 | 17.22 | 66.59 | 2.59 | 0.150 | 26,331 | 10,162 |
| APPENDIX A11 5/8 in. Wall | 10.93 | 52.96 | 18.24 | 71.2 | 2.84 | 0.153 | 24,546 | 9,594 |

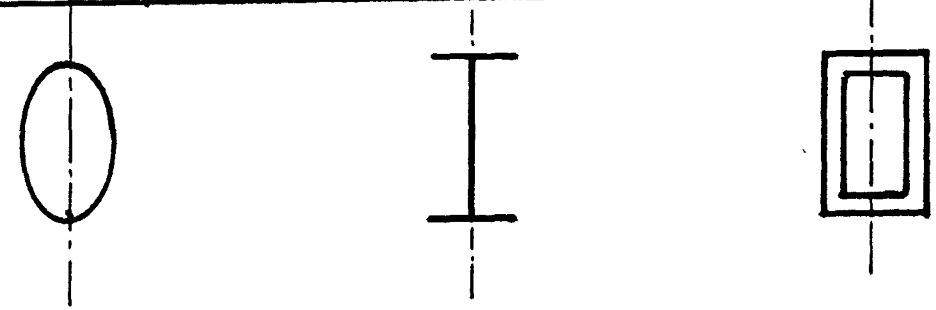
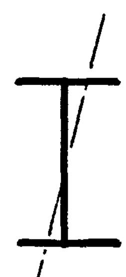
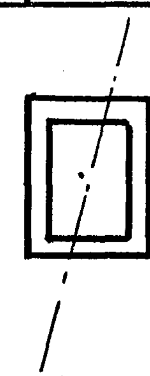


Table 5-3 Comparative Section Analysis and Corresponding Stresses of Arm Cross-Sections in Bending at 14 Degrees to Normal.

| Cross-Section Design | Area | $I_x$ | $I_y$ | J Polar Moment | Wt. lbs per in. Section | $\frac{A}{J}$ | $\sigma_x$ p.s.i. | $\sigma_y$ p.s.i. | p.s.i. |
|---|---|---|---|---|---|---|---|---|---|
| APPENDIX A12 Existing Oval Section | 17.87 | 48.14 | 14.82 | 62.96 | 4.62 | 0.282 | 26,506 | 12,429 | 15,670 |
| APPENDIX A13 I Beam Section 7/8 in. Flange 3/4 Webb | 9.69 | 52.66 | 9.29 | 61.95 | 2.59 | 0.160 | 27,170 | 26,738 | 7,327 |
| APPENDIX A14 * | 10.94 | 50.93 | 20.27 | 71.2 | 2.84 | 0.154 | 26,506 | 11,408 | 11,604 |

* Assumes a half in. radius on outside corners

this torque as it is a crucial component of the stresses. For this reason the polar moment is of special interest. Having surveyed the present design cross-section we can regard that as a bogey because it is presently meeting the application. Other designs then should be measured against this design. The A/J column in the tables is simply a ratio of efficiency of material usage. The lower this value, the greater the efficiency. As can be seen from this data, a box section between 9/16 ins. and 5/8 ins. wall exceeds the oval section on all counts, is half the weight per design inch and has double the efficiency.

Table 5-3 considers the three basic shapes when acted upon by a bending moment applied at 14 degrees to normal (from information advanced by TACOM). Again the box section is clearly superior.

5.3.1 Using this information, a box section with an 0.625 in. wall was designed for the offset arm. Material was removed from around the end hubs where it appeared that these were over designed.(see Fig 5-1). The internal core for the box section is connected to the spindle hole cores so that a single core is used to make the complete casting.

## 5.4. Material Selection

5.4.1. Material Characterization. Concurrent with the design work, the issue of material characterization was worked on. Not only did this result in much needed information in general, but it also dictated the particular heat-treatment that would be used on the road wheel arms.

5.4.2. Characterization Method. Two hundred and fifty "keel block" tensile test bars and 500 charpy impact test bars were cast (see Fig 5-2). These were all cast in the same heat of iron with a routine ferritic iron chemistry, Table 4-1b. The reason for making them all from the same heat was to eliminate chemistry as a variable in this study. Since isothermally transformed nodular iron has a propensity to work harden because of the transformation of retained austenite to martensite at the interface, it was judged that machining the test bars after heat-treatment would skew the results. All bars were therefore machined prior to heat-treatment. The austenitizing temp- was maintained at 1650$^{O}$F in every case and 25 tensile test bars and 50 charpy bars were processed at each quench temperature. The austenitized bars were quenched at temperatures from 400$^{O}$F to 800$^{O}$F in 50$^{O}$F increments. After one hour in the salt, 5 bars each of tensile and 10 of charpy were removed and rinsed off in water. In this way, a profile was obtained over 4 hours quench-soak time at one hour intervals. Austenitizing time was maintained at 3 hours at temperature in every case. The tensile bars were then pulled and the results were recorded. The charpy bars, five notched and five unnotched were impacted and the results were recorded. These data are shown graphically in APPENDIX B. Selected photomicrographs are shown in APPENDIX C.

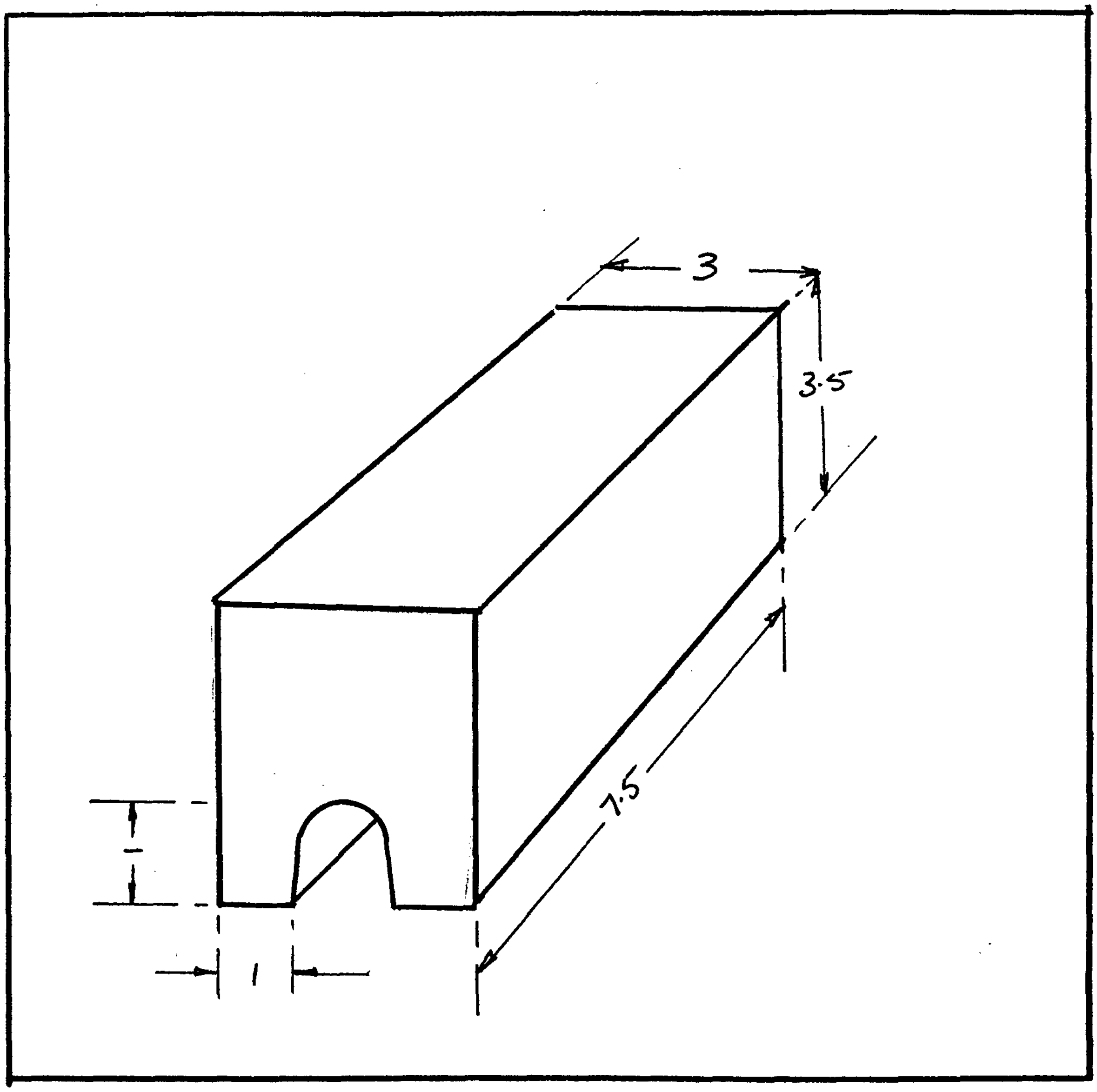



Fig. 5-2. Test Bar Keel Block. Test bars are cut from the two lower ribs and machined into standard $\frac{1}{2}$ in. diameter tensile bars.

5.4.3. Characterization at Temperature. The contract required that the material be characterized at temperatures from -60°F to 230°F. This was done by picking a quench temperature that resulted in an optimum of mechanical properties and processing 40 more tensile and 40 unnotched charpy bars at 700°F quench temperature. A thermocouple was welded to each bar and five bars were tensile tested or impacted at each temperature. The results of this study are shown in APPENDIX D. A sketch of the apparatus is shown in Fig 5-3.

5.4.4. Additional Trials. In the course of this investigation, two other trials were made. One was to look at the effects of austempering a second time on a group of bars where a furnace failure had interrupted the process, and a second was to see what effect molybdenum might have on the qualities of the material( Table 4-le). These results are shown in APPENDIX E.

5.4.5. Discussion of Results As might be expected, the lower quench temperatures result in test bars with higher hardness values, while the higher quench temperatures give test bars with lower values. Elongation values, however, are the reverse of this,reaching nearly 10 percent at the 700°F quench. Tensile strengths of over 200,000 p.s.i. are easily obtainable in the 550°F quenches but elongation at this level is barely 5 percent. These relationships are clearly shown in the bar chart, Fig 5-4. The effect of low or high ambient temperatures is minimal at the temperatures investigated, indicating that if nodular iron is to be used at temperatures to -60°F, it should be austempered in the 700°F range for best results and safety. The net result of this characterization is that isothermally heat-treated nodular iron can be tailored to many applications normally reserved for alloy steels and has cryogenic applications. On the negative side is the strong evidence, as indicated by the charpy notched bars, that the material is quite notch sensitive. Untill a method can be found to minimize this problem, every effort must be made in design to eliminate sharp angles and other stress raisers in a component. It is also essential that in the course of manufacturing, machining or grinding notches into a part must be avoided at all costs. Reheattreating parts does not appear to be advisable if optimum qualities are to be obtained. Even when austenitizing at the higher temperature of 1700°F, some loss in mechanical properties to the extent of 3-4 percent was found. The addition of 0.4 percent molybdenum seemed to have little effect except to make the point of optimum properties a little more critical with respect to time in the salt (at least in the standard test bar section). This is in contradiction to published literature.

## 5.5. Road Wheel Arm, Material Selection.

Using the material characterization data, a quench temperature of 650°F was selected for the redesigned road wheel arms. Although the 700°F temperature properties look better, it was thought that the mass of

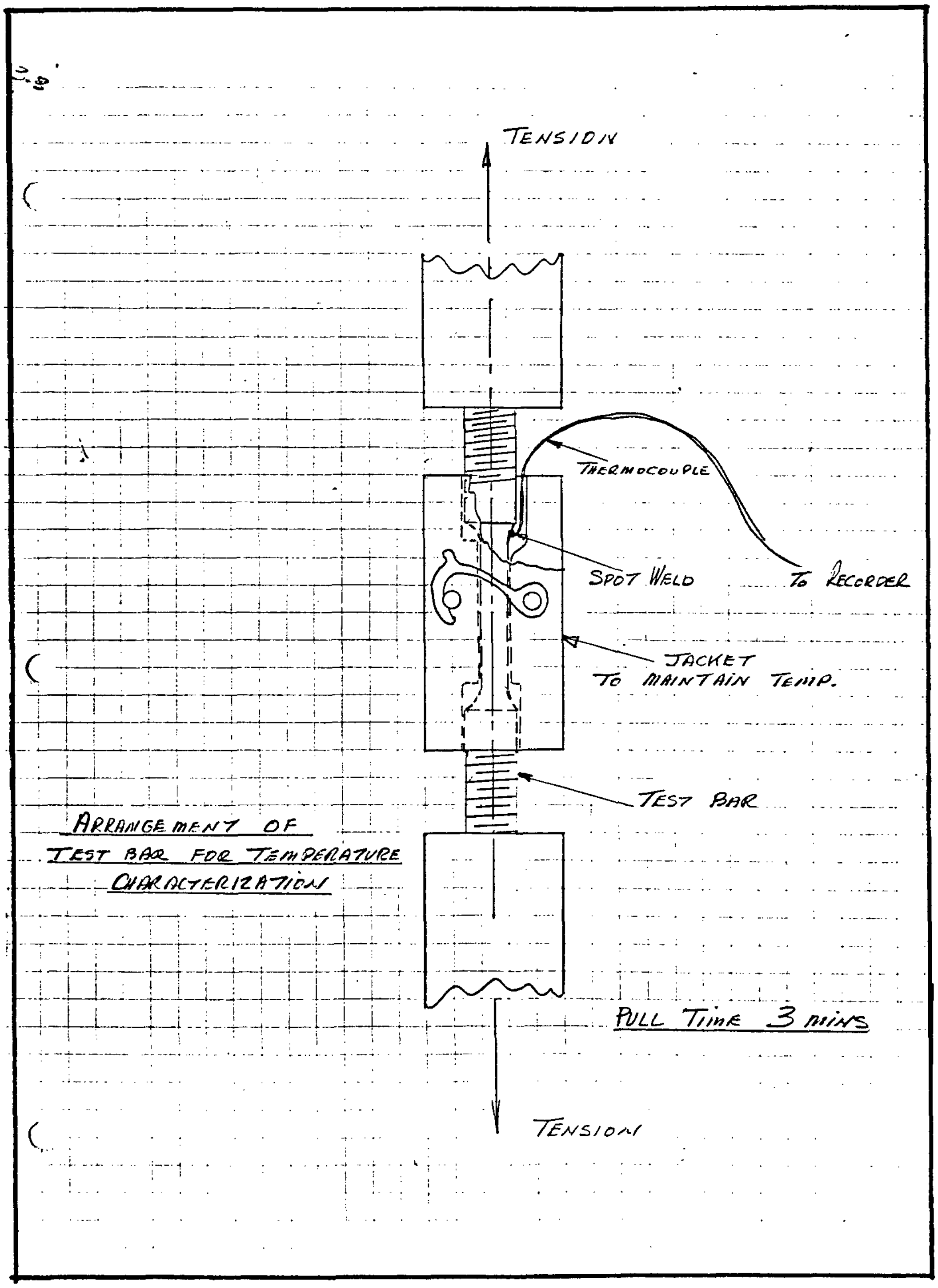



Fig. 5-3. Sketch Showing the Arrangement of Apparatus to obtain Temperature Characterization.

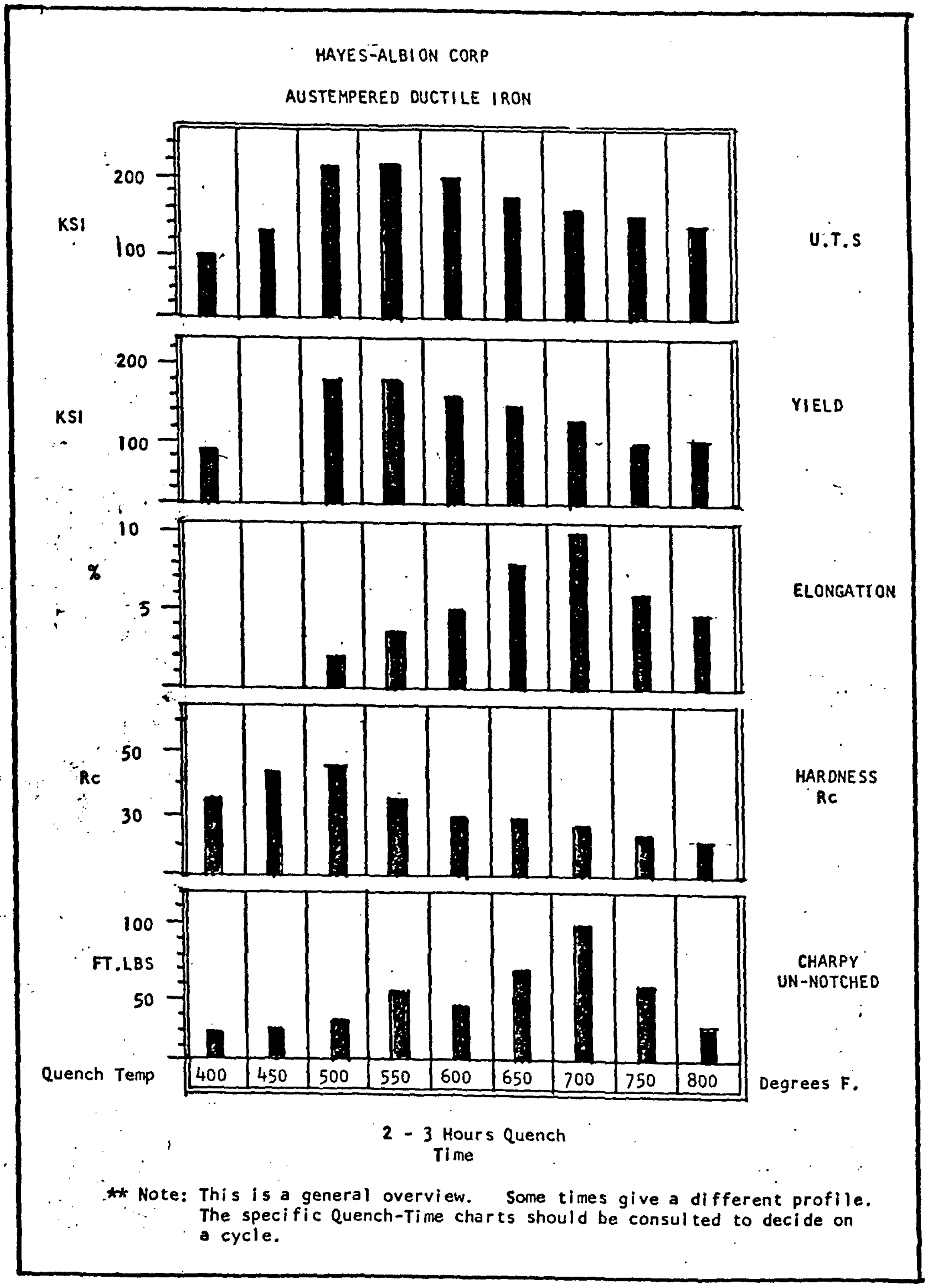



Fig. 5-4. Bar Chart Showing the Relationships between the Various Mechanical Qualities.

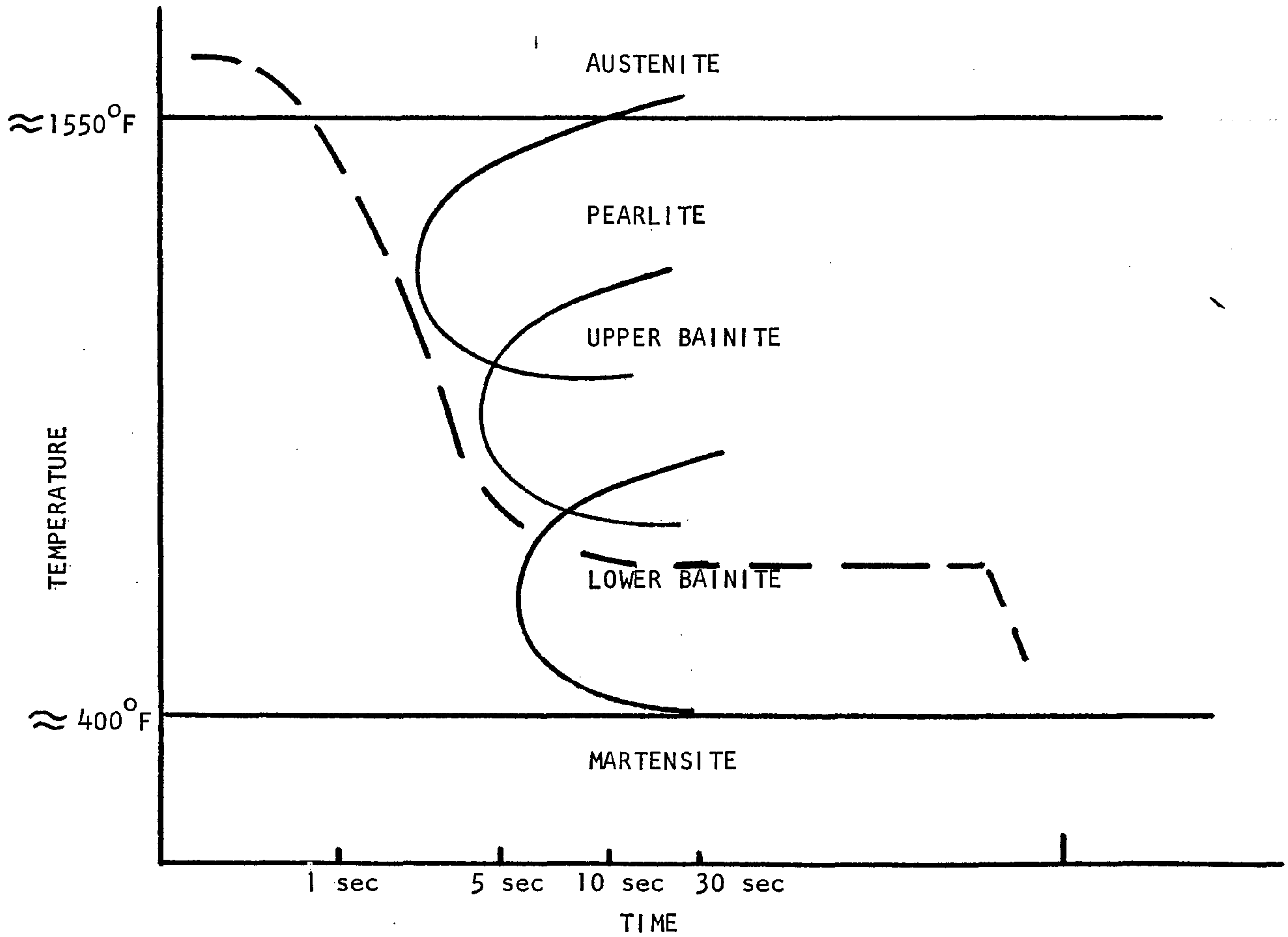



Fig. 5-5. Time-Temperature Diagram Showing the Precipitious Nature of the Quench needed to Avoid the Pearlite Field.

the arm would behave in the quench as if it were at the higher temperature. It was also decided, in deference to published research, that 0.25 percent molybdenum would be beneficial in allowing for a little more time for the transition to be effected. It was thought that the box section of the arm would require that most of the temperature drop occur from the outside and anything that pushed the "nose" of the pearlite curve towards the right of the transformation diagram would be helpful (see Fig 5-5).

5.5.1. First Sample Road Wheel Arm. A plastic pattern and two half cast-aluminum core boxes were constructed (see Fig 5-6 and 5-7). First castings were sectioned to check for uniform wall thickness. Afterwards a casting was made for static testing. This casting was X-rayed for integrity and metallurgically approved. It was machined complete then isothermally heat-treated and assembled.

5.5.2. First Static Test. For the first static test, the arm was mounted on a special shaft that was attached to a circular mounting plate. This plate was doweled and bolted to the test bed in such a way that a force of 20,000 pounds could be applied to the spindle. From a brittle lacquer survey, 15 strain gage locations were chosen (se Fig 5-8). Loads in 1000-pound increments were applied to the spindle and the strain recorded. As shown in Fig 5-9, these strains have a straight line relationship. The complete results are shown in APPENDIX F.

5.5.3. Discussion of the Static Test Results. It was obvious from the pattern of strain that besides a bending moment in the arm, a torque was also at work. The combination of these forces contributed to high stresses in certain areas, particularly at the knee of the offset. It was then decided to redesign the arm, attempting to reduce some apparent stresses of up to 38,000 p.s.i. at 20,000 pounds load. The redesign was a smoother transition of the arm into the hubs and an increase in the internal radii. At this time, an additional request for dynamic testing came from TACOM and plans were made to do this.

5.5.4. Second Static Test. Having made modifications to the arm design a second cast was made. Chemistry and test bar results from keel blocks cast in the same molds are shown in Tables 4-1c and 5-4.

5.5.5. Second Static Test Arrangement. More information about the application and duty of the component was now made available. A test rig was made in which the arm was held rigidly by a splined shaft extending six inches from both sides of the arm. The arm was inclined 17 degrees to the vertical and 14 degrees off the perpendicular in that plane. A load of 18,000 pounds was to be applied at 90 degrees to the spindle and 4,500 pounds normal to the spindle from the arm towards the wheel. This loading resulted in a load of 18,554 pounds being applied to the spindle at an angle of 14 degrees to the longitudinal centerline and away from the vehicle (se Fig 5-10). This figure shows the test setup with the load being applied as a pull towards the cylinder.

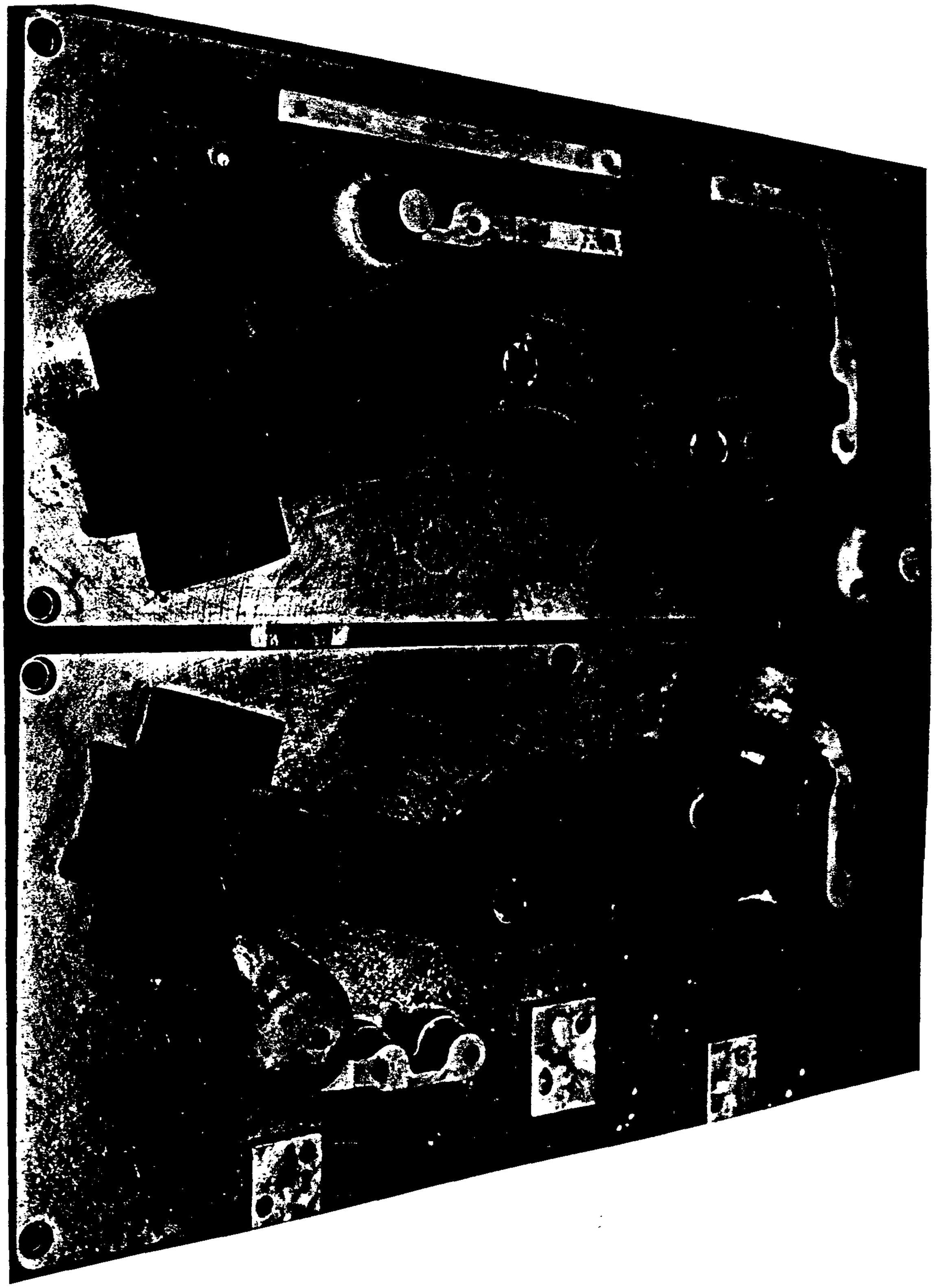


Fig. 5-6. Pattern Equipment used to produce the Road Wheel Arm.

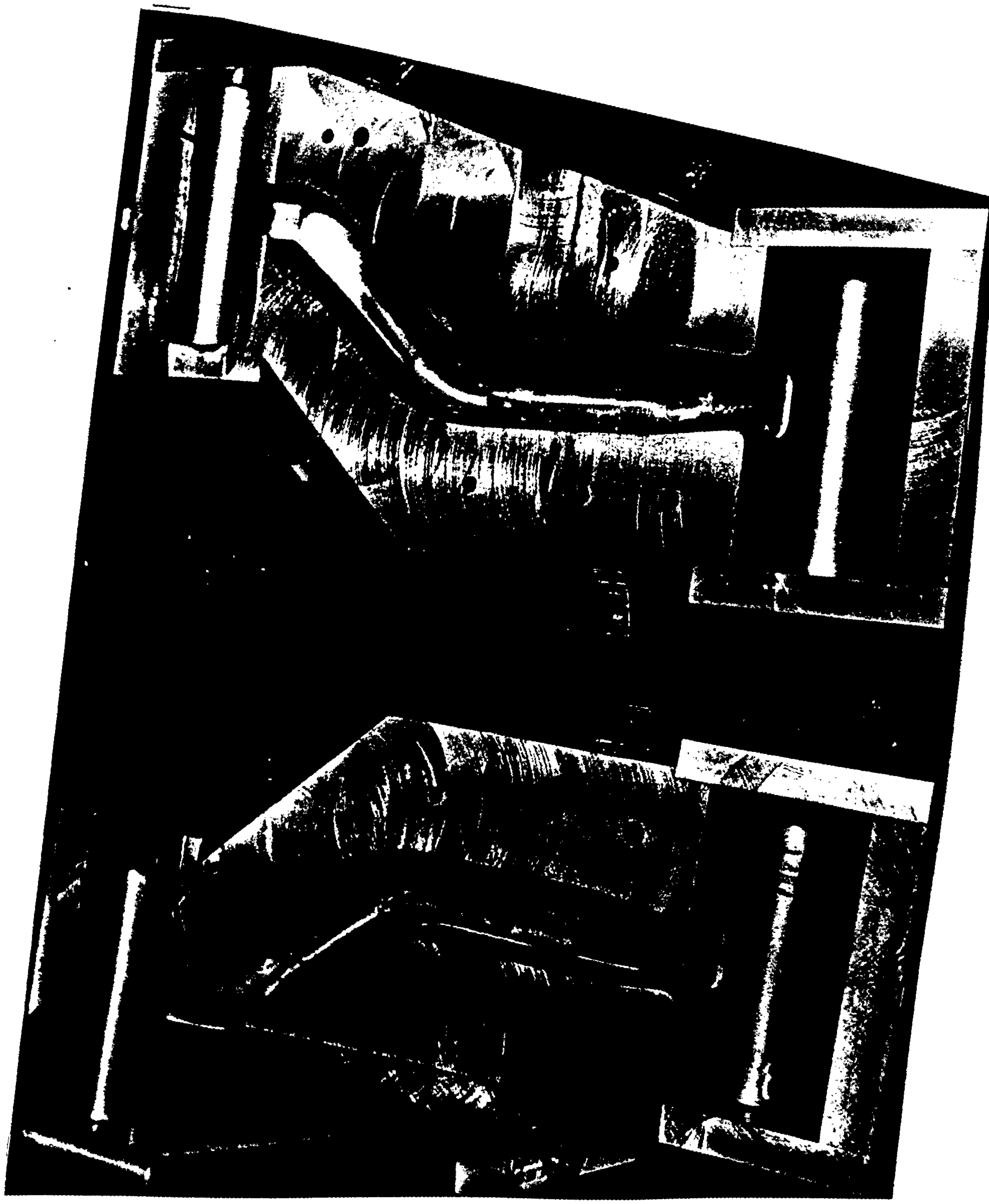


Fig. 5-7. Core Boxes used to Produce The Road Wheel Arm

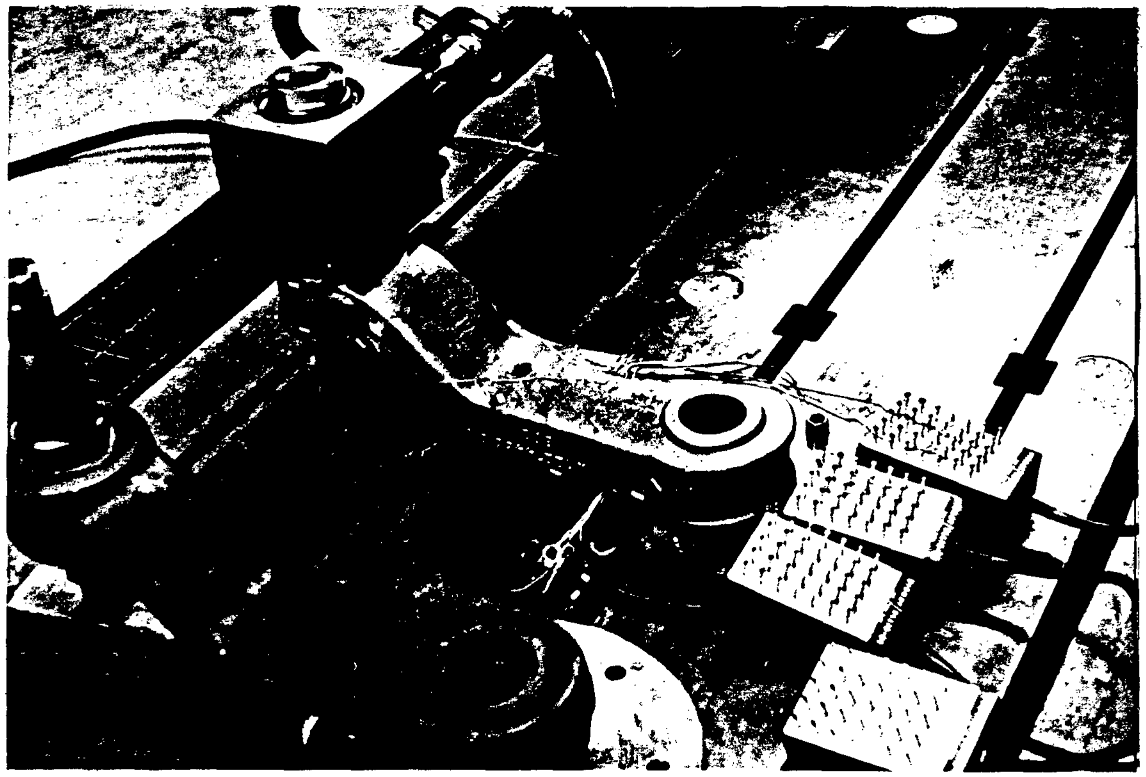


Fig.5-8 First Static Test Set-up. Comparison of the casting with the forging can be seen in this picture. Multiple strain gage attachment posts are shown in the lower right-hand corner.

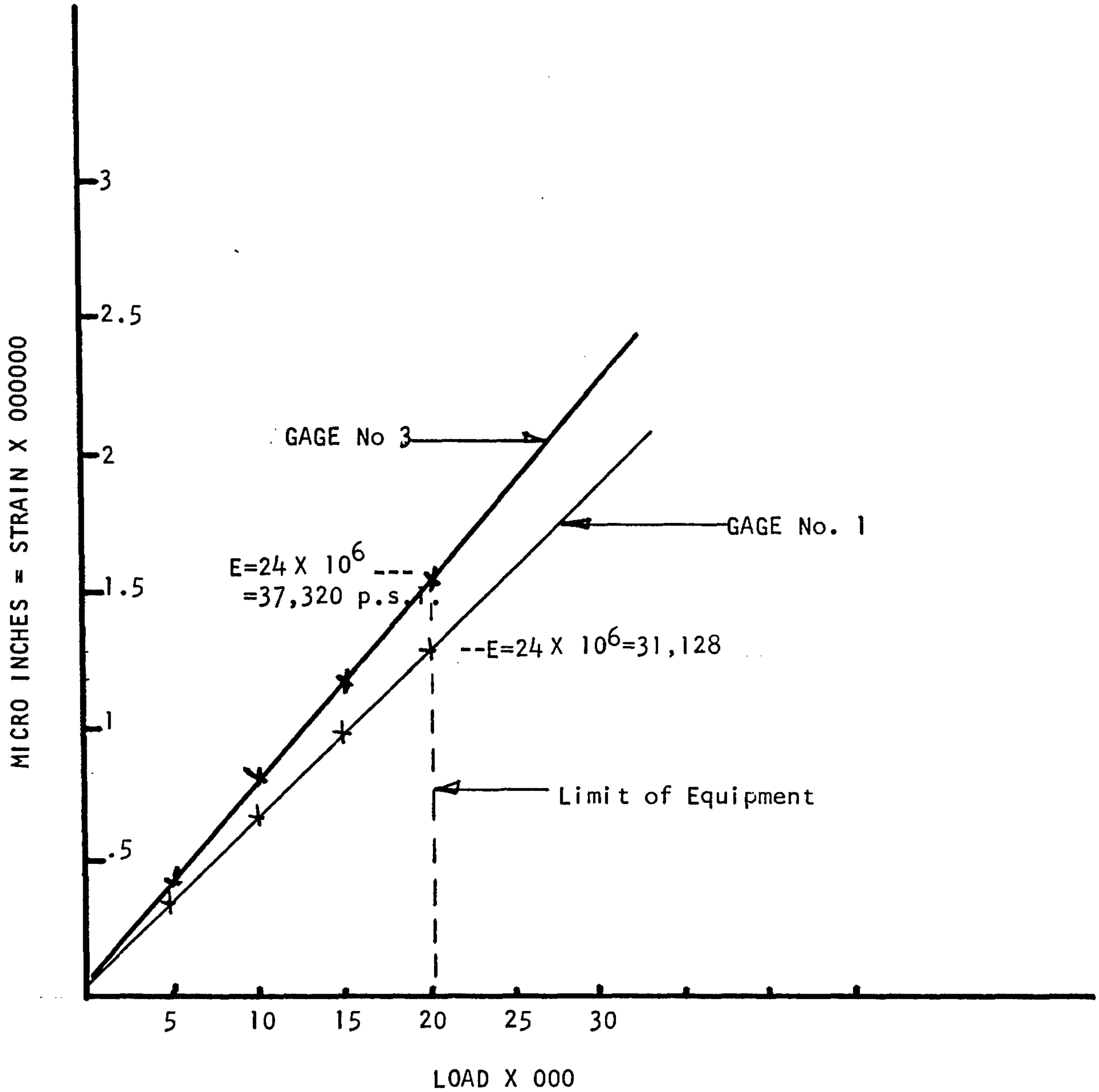



Fig. 5-9. Graph of Readings from Highest Value Strain Gages
E = Young's Modulus of Elasticity. The value $24 \times 10^6$ was found experimentally during this project.

Table 5-4. Test Bar Results from BDI with the Chemistry Shown in Table 4-1c. This is questionable material.

| Tensile p.s.i. | Yield p.s.i. | Elongation percent |
|---|---|---|
| 165,000 | 135,000 | 2.5 |

Fig. 5-10. Second Static Test Set-up. This Set -up is also that Used for the Dynamic Testing. Notice that the power cylinder is at a lateral as well as a longitudinal angle to the center line of the fixture

Table 5-5. Second Static Test Strain Gage Results

| LOAD | 1 | 3 | 2 | 15 | 12 | 11 |
|---|---|---|---|---|---|---|
| | Strain Gage Numbers, Microinches | | | | | |
| 1000 | -36 | -46 | -48 | 14 | 50 | 94 |
| 2000 | -75 | -111 | -92 | 19 | 95 | 190 |
| 3000 | -116 | -117 | -133 | 24 | 139 | 282 |
| 4000 | -150 | -235 | -173 | 29 | 179 | 367 |
| 5000 | -187 | -296 | -214 | 34 | 222 | 456 |
| 6000 | -225 | -360 | -257 | 39 | 267 | 551 |
| 7000 | -261 | -419 | -298 | 44 | 308 | 640 |
| 8000 | -300 | -483 | -343 | 49 | 354 | 737 |
| 9000 | -337 | -544 | -384 | 54 | 398 | 831 |
| 10000 | -370 | -599 | -424 | 59 | 436 | 914 |
| 11000 | -407 | -659 | -467 | 64 | 480 | 1007 |
| 12000 | -446 | -720 | -512 | 69 | 525 | 1103 |
| 13000 | -482 | -778 | -554 | 74 | 567 | 1194 |
| 14000 | -518 | -834 | -596 | 79 | 609 | 1283 |
| 15000 | -552 | -889 | -636 | 84 | 649 | 1369 |
| 16000 | -590 | -950 | -682 | 90 | 695 | 1467 |
| 17000 | -624 | -1004 | -722 | 95 | 736 | 1554 |
| 18000 | -660 | -1061 | -765 | 100 | 778 | 1645 |
| 19000 | -697 | -1120 | -810 | 105 | 823 | 1740 |
| 20000 | -721 | -1158 | -839 | 109 | 852 | 1804 |

5.5.6. Second Static Test Results. From a brittle lacquer survey, six strain gage sites were selected. These were approximately in the same positions as the first strain gage survey and were numbered accordingly. Table 5-5 shows the results.

5.5.7. First Dynamic Test Procedure. Initially a 20,000 pound capacity load cell was calibrated using a Satec Universal Test System and a Hewlett-Packard X,Y Plotter to record the calibrated curve. The load cell was then placed into a test apparatus which consisted of an MTS Testline 820 Structural Test System, a bolted down frame, and a tank arm assembly. With an upper limit of 19,600 pounds and a lower limit of 2,000 pounds, the arm was cycled at 2.5 hertz. Each day the load cell was shunt calibrated to correct any electronic drift that might have occured. The load cell's shunt calibration limits and the attenuator's displacement were recorded with a Gould brush recorder and documented. Failure of the arm occurred at 596,720 cycles against a 650,000 target.

5.5.8. Analysis of Failure. Fig. 5-11 illustrates the location of the fracture. It was determined that the fracture originated in the tapped hole, propagating across the area of high stress caused by the bending and torque moments. The substandard material compounded the failure.

5.5.9. Third Static Test. In anticipation of this failure, a second cast was made with an analysis shown in Table 4-1c . This is a base nodular iron with an addition of molybdenum.(note that the Mo addition is almost half the amount in the first dynamic test). Test bars from this heat gave the results shown in Table 5-6. This is excellent material, but in particular the elongation is twice that of the previous dynamic test specimens. This would indicate that Mo additions must be made with caution. Current thinking is that Mo should not exceed 0.25 percent. No holes were drilled in the arm. Two strain gage rosettes were attached in areas of high stress. The readings from these rosettes are shown in Table 5-7, with positions shown in Fig.5-12. The highest strain of 1,550 microinches translates to 37,200 p.s.i.

5.5.10. Second Dynamic Test. Dynamic testing began under the same conditions as explained in 5.5.7. At 1,037,620 cycles, the test was terminated. The tank arm was then removed from the apparatus and given a Magnaflux test to check for cracks. None was found.

5.5.11. Analysis of Second Dynamic Test. It is obvious from the foregoing results that the arm design and material are adequate for the application. Data now obtained would allow fine tuning of the design and add even further to the safety factor and life.

5.5.12. Manufacture of the 14 Contract Arms. The required completion

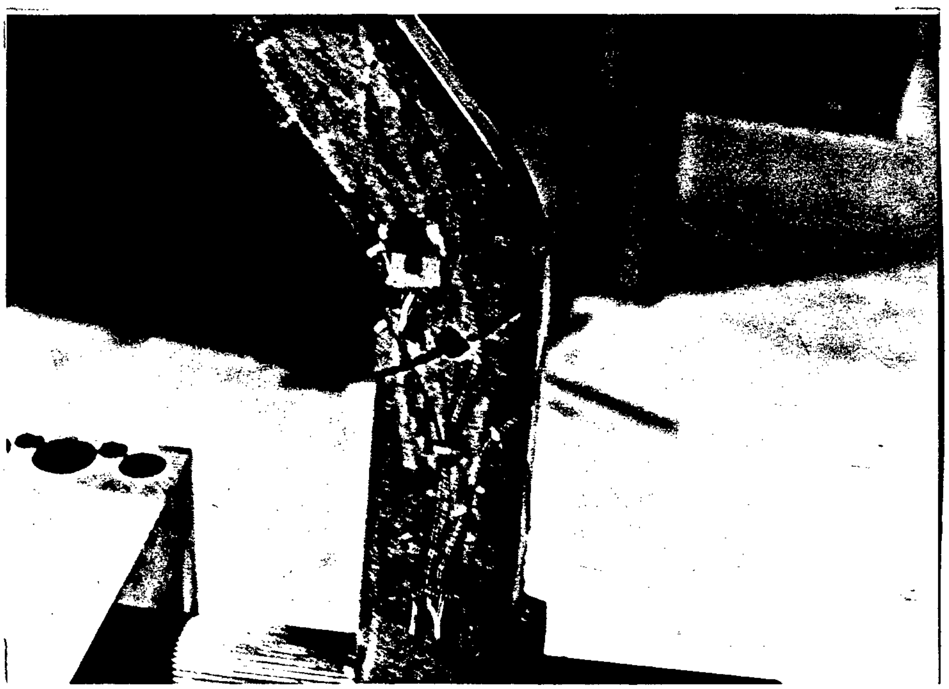


Fig. 5-11. Fracture of First Dynamic Test Arm. The Tapped hole was originally installed in order to allow a filler to be installed into the interior of the arm.

Table 5-6. Test Bar Results of BDI in Second Dynamic Test Specimen. This is excellent material.

| Bar No. | Tensile p.s.i. | Yield p.s.i. | Elongation percent |
|---|---|---|---|
| 1 | 195,400 | 165,000 | 5 |
| 2 | 196,600 | 163,400 | 6 |
| 3 | 193,900 | 163,300 | 4 |
| 4 | 196,400 | 166,800 | 5 |
| 5 | 194,800 | 167,500 | 5 |

Table 5-7. Readings from Rosett Strain Gages, Second Dynamic Test

ROAD WHEEL ARM STRAIN READINGS
TEST #2

GAGES

| | Upper Rosett | | | Lower Rosett | | |
|---|---|---|---|---|---|---|
| Load | 0 | 1 | 2 | 3 | 4 | 5 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1K | 83 | 40 | 5 | 66 | 33 | -32 |
| 2K | 160 | 79 | 10 | 106 | 67 | -40 |
| 3K | 240 | 122 | 14 | 146 | 101 | -54 |
| 4K | 318 | 162 | 20 | 186 | 136 | -63 |
| 5K | 394 | 203 | 25 | 224 | 172 | -73 |
| 6K | 471 | 246 | 31 | 261 | 205 | -84 |
| 7K | 548 | 288 | 38 | 300 | 238 | -93 |
| 8K | 626 | 331 | 45 | 337 | 272 | -101 |
| 9K | 702 | 374 | 51 | 375 | 308 | -110 |
| 10K | 780 | 417 | 58 | 412 | 342 | -117 |
| 11K | 859 | 460 | 64 | 451 | 375 | -126 |
| 12K | 934 | 501 | 71 | 488 | 412 | -131 |
| 13K | 1013 | 544 | 77 | 527 | 448 | -139 |
| 14K | 1090 | 586 | 83 | 567 | 483 | -144 |
| 15K | 1166 | 631 | 90 | 605 | 521 | -153 |
| 16K | 1244 | 670 | 97 | 646 | 560 | -157 |
| 17K | 1322 | 713 | 106 | 687 | 598 | -166 |
| 18K | 1398 | 755 | 110 | 728 | 634 | -173 |
| 19K | 1474 | 799 | 117 | 770 | 673 | -180 |
| 20K | 1550 | 838 | 123 | 812 | 709 | -187 |

Principal strains and their corresponding stresses were calculated based on a 20,000 pound load:

| | | |
|---|---|---|
| Upper Rosette: | $\epsilon$ Max = 1,903 $\mu$ in. per in. | $\sigma$ Max = 43,267 p.s.i. |
| | $\epsilon$ Min = 229 $\mu$ " | $\sigma$ Min = 11,999 p.s.i. |
| | $\gamma$ Max = 2,132 $\mu$ " | $\tau$ Max = 23,451 p.s.i. |
| | $\theta$ Max = $45^0$ | |
| Lower Rosette | $\epsilon$ Max = 1,079 $\mu$ in. per in. | $\sigma$ Max = 22,023 p.s.i. |
| | $\epsilon$ Min = -109 $\mu$ " | $\sigma$ Min = 7,338 p.s.i. |
| | $\gamma$ Max = 1,270 $\mu$ " | $\tau$ Max = 18,060 p.s.i. |
| | $\theta$ Max = $32.5^\circ$ | |

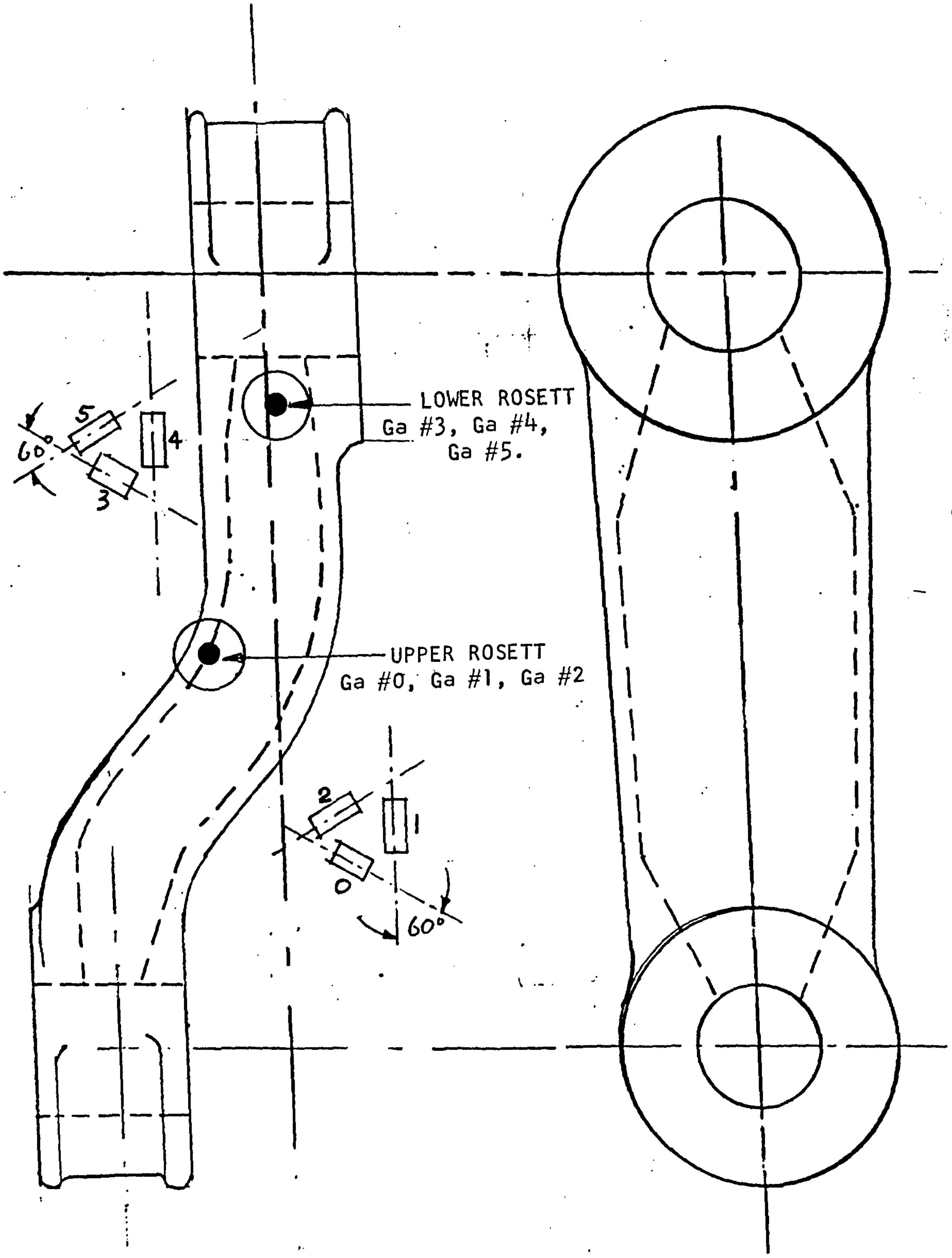



Fig. 5-12. Position of Rosett Strain Gages. These gages are positioned so that one is normal and the other two are at an angle of 45° to No 1 and 90° to each other.

of the 14 arms was then completed without incident. The fact that the heat-treatment was done after machining required that an allowance be made for growth of 0.002 ins. per inch. Heating the arm in order to shrink the spindles in place was done by induction and held to a maximum of 400°F, the spindles being frozen to -100°F. An application of Loctite 620 was made to the inboard side of the splined spindle where it mates with the arm to seal off the spline from oil seepage. The weld called for on the outboard end of the splined spindle was done by heliarcing a silver solder into a "V". No metallurgical damage occurred as this was only a seal and not a structural weld.

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APPENDIX A

COMPARATIVE CALCULATIONS

ON

THREE DIFFERENT CROSS-SECTIONS

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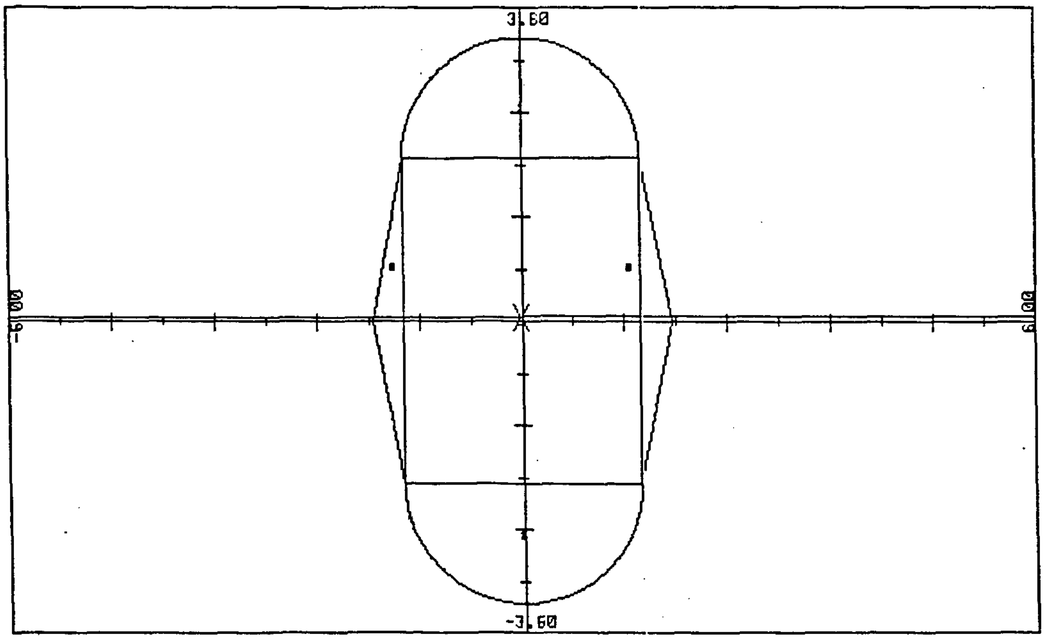
GENERAL SECTION 1
AREA=17.78
Imax=50.35
Imin=12.15

HAYES-ALBION CORPORATION
SECTION ANALYSIS



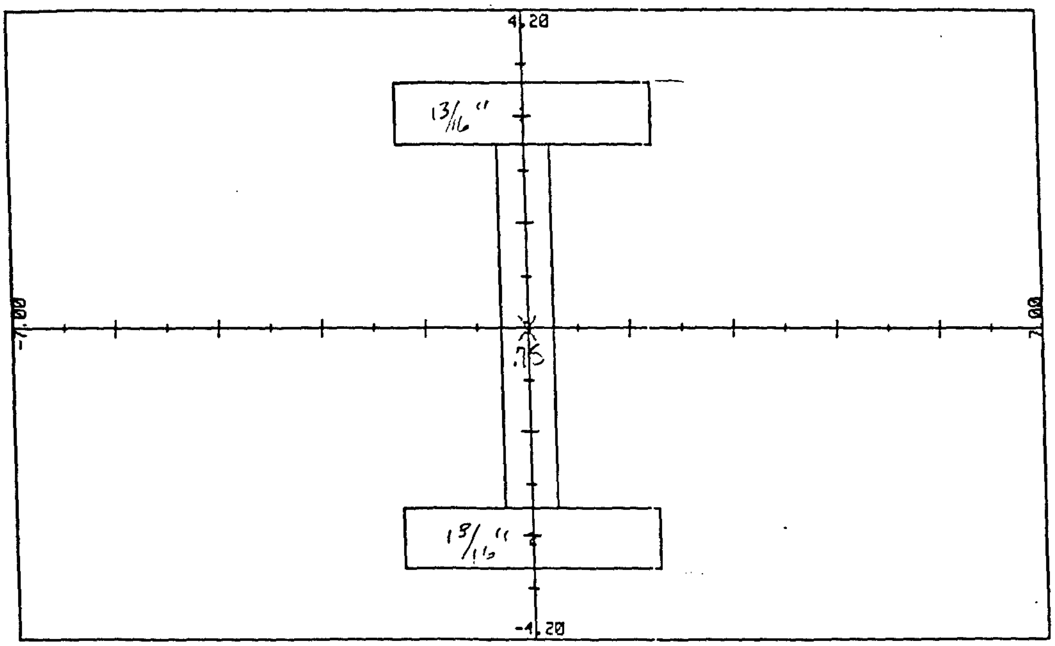

COMPOSITE OF SECTIONS:

| | | | | |
|---|---|---|---|---|
| | Area= | 17.7758 | | |
| CENTER OF GRAVITY: | Gx= | -0.010 | Gy= | 0.049 |
| INERTIA: | Ix= | 50.3456 | Iy= | 12.1498 |
| PRODUCT OF INERTIA: | Pxy= | -0.0715 | | |
| | Imax= | $\boxed{50.3457}$ | Imin= | 12.1497 .1495 |
| ANGLE: | 0.11 | (Deg) | | J = [illegible] |

File Name: T-ARM

HAYES-ALBION CORPORATION
SECTION ANALYSIS

A.[illegible] .254




COMPOSITE OF SECTIONS:

| | | | | |
|---|---|---|---|---|
| | Area= | 9.3410 | | |
| CENTER OF GRAVITY: | Gx= | 0.000 | Gy= | 0.000 |
| INERTIA: | Ix= | 53.5320 | Iy= | 5.9738 |
| PRODUCT OF INERTIA: | Pxy= | 0.0000 | | |
| | Imax= | 53.5320 | Imin= | 5.9738 |
| ANGLE: | 0.00 (Deg) | | | |

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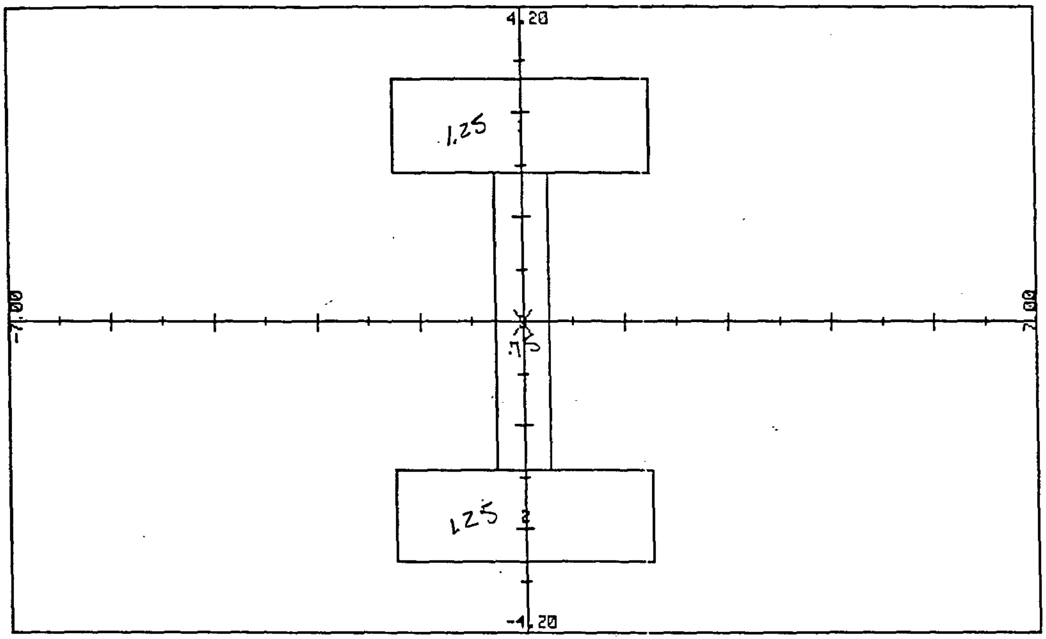
HAYES-ALBION CORPORATION
SECTION ANALYSIS

F2-2

HAYES-ALBION CORPORATION
SECTION ANALYSIS




COMPOSITE OF SECTIONS:

| | | | | |
|---|---|---|---|---|
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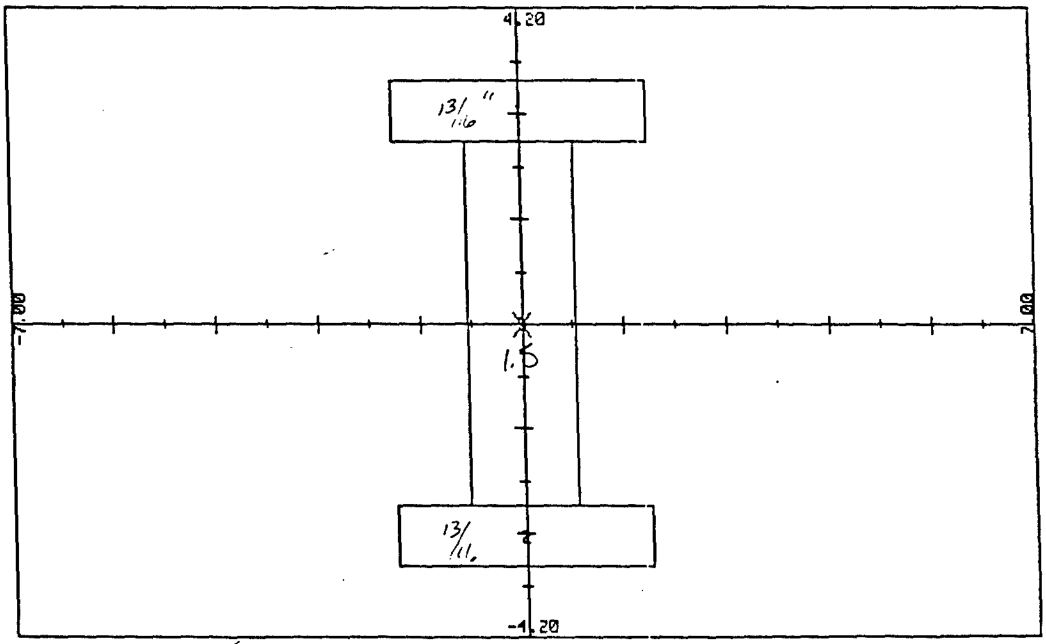
| CENTER OF GRAVITY: | Gx= | 0.000 | Gy= | 0.000 |
| INERTIA: | Ix= | 65.4323 | Iy= | 9.0729 |
| PRODUCT OF INERTIA: | Pxy= | 0.0000 | | |
| | Imax= | 65.4323 | Imin= | 9.0729 |
| ANGLE: | 0.00 (Deg) | | | |

File Name:

HAYES-ALBION CORPORATION
SECTION ANALYSIS

HAYES-ALBION CORPORATION
SECTION ANALYSIS




COMPOSITE OF SECTIONS:

| | | | | |
|---|---|---|---|---|
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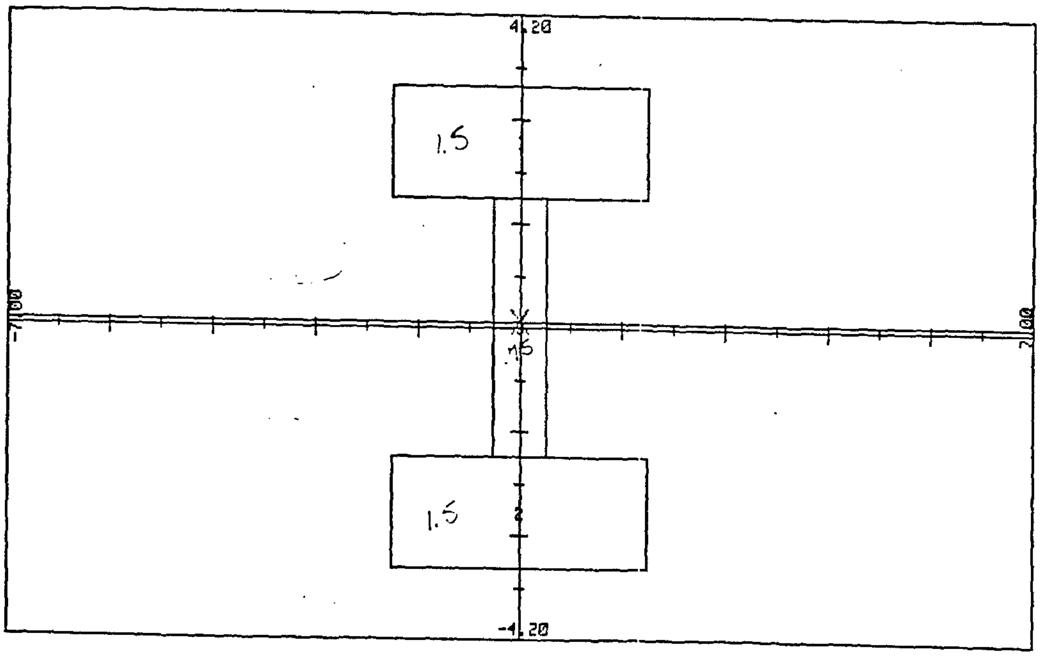
| INERTIA: | Ix= | 60.7775 | Iy= | 7.1738 |
| PRODUCT OF INERTIA: | Pxy= | 0.0000 | | |
| | Imax= | 60.7775 | Imin= | 7.1738 |
| ANGLE: | 0.00 (Deg) | | | |

File Name:

$J = I_x + I_y =$ [illegible]

HAYES-ALBION CORPORATION
SECTION ANALYSIS

HAYES-ALBION CORPORATION
SECTION ANALYSIS




COMPOSITE OF SECTIONS:

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|---|---|---|---|---|
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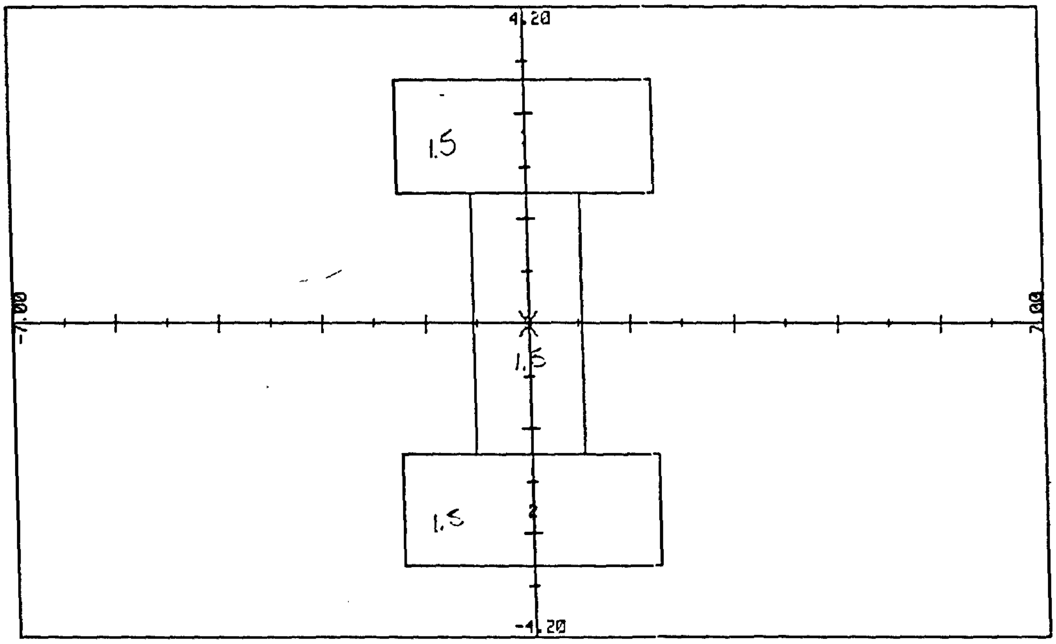
| INERTIA: | Ix= | 70.2734 | Iy= | 10.8418 |
| PRODUCT OF INERTIA: | Pxy= | 0.0000 | | |
| | Imax= | 70.2734 | Imin= | 10.8418 |
| ANGLE: | 0.00 | (Deg) | | |

File Name:

HAYES-ALBION CORPORATION
SECTION ANALYSIS

HAYES-ALBION CORPORATION
SECTION ANALYSIS




COMPOSITE OF SECTIONS:

| | | | | |
|---|---|---|---|---|
| | Area= | 15.7500 | | |
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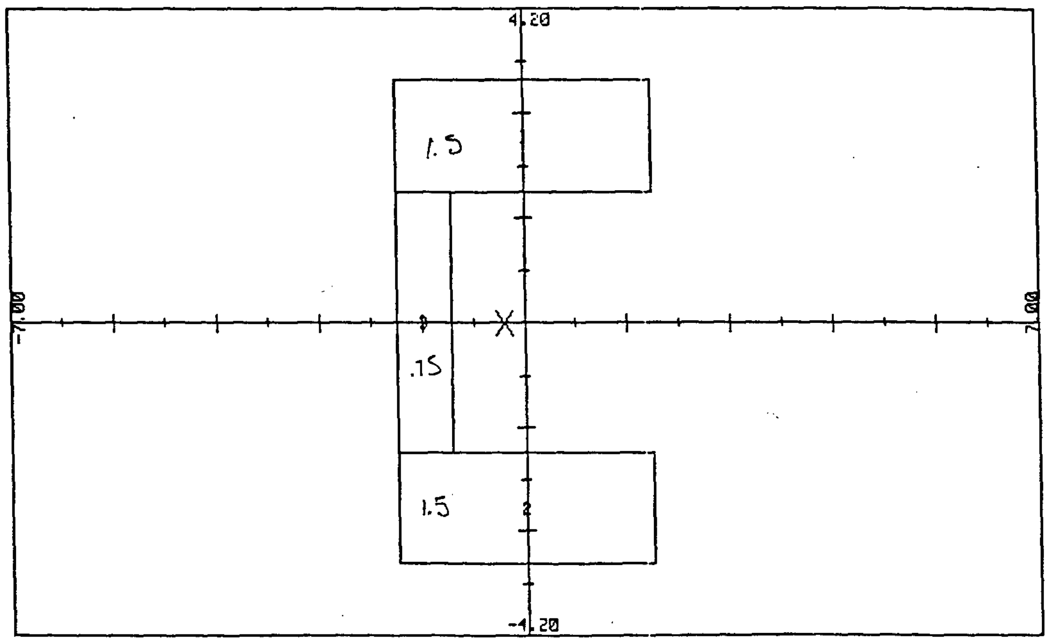
| INERTIA: | Ix= | 72.9531 | Iy= | 11.7031 |
| PRODUCT OF INERTIA: | Pxy= | 0.0000 | | |
| | Imax= | 72.9531 | Imin= | 11.7031 |
| ANGLE: | 0.00 (Deg) | | | |

File Name:

HAYES-ALBION CORPORATION
SECTION ANALYSIS

HAYES-ALBION CORPORATION
SECTION ANALYSIS



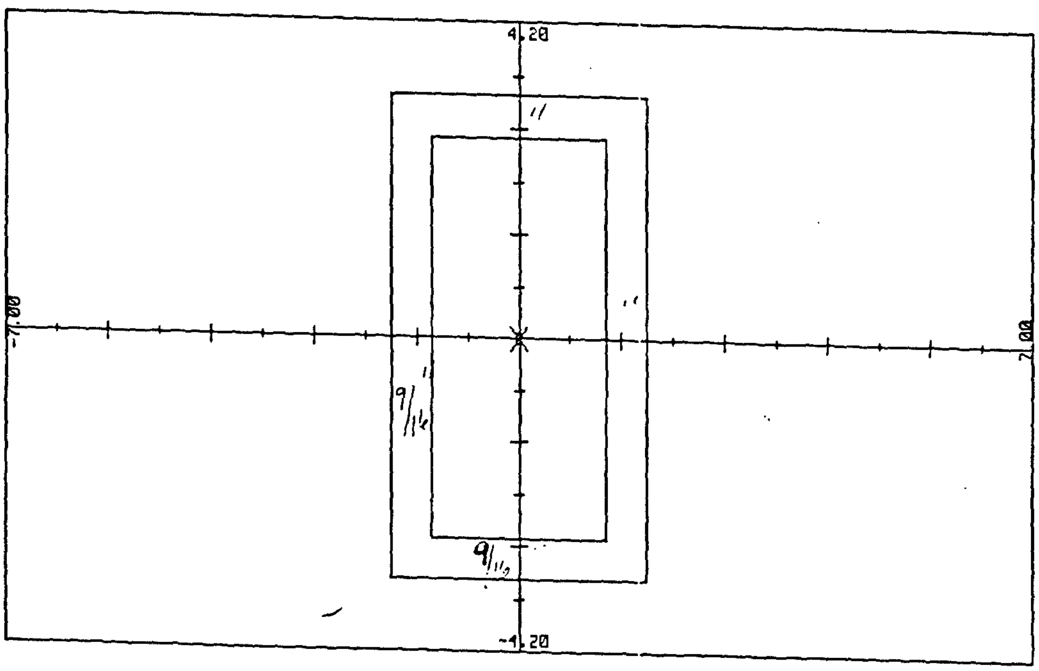

COMPOSITE OF SECTIONS:

| | | | | |
|---|---|---|---|---|
| | Area= | 13.1250 | | |
| CENTER OF GRAVITY: | Gx= | -0.275 | Gy= | 0.000 |
| INERTIA: | Ix= | 70.2734 | Iy= | 14.8121 |
| PRODUCT OF INERTIA: | Pxy= | 0.0000 | | |
| | Imax= | 70.2734 | Imin= | 14.8121 |
| ANGLE: | 0.00 (Deg) | | | |

File Name:

HAYES-ALBION CORPORATION
SECTION ANALYSIS

HAYES-ALBION CORPORATION
SECTION ANALYSIS




COMPOSITE OF SECTIONS:

| | | | | |
|---|---|---|---|---|
| | Area= | 9.9814 | | |
| CENTER OF GRAVITY: | Gx= | 0.000 | Gy= | 0.000 |
| INERTIA: | Ix= | 49.3693 | Iy= | 17.2170 |
| PRODUCT OF INERTIA: | Pxy= | 0.0000 | | |
| | Imax= | 49.3693 | Imin= | 17.2170 |
| ANGLE: | 0.00 (Deg) | | | |

File Name:

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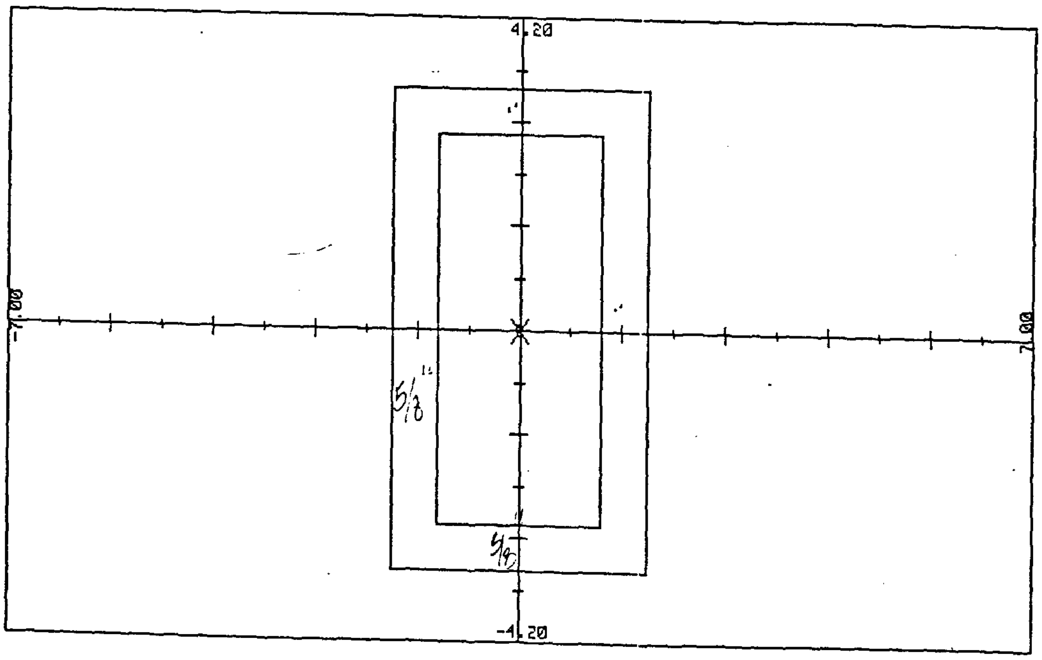
SECTION ANALYSIS

HAYES-ALBION CORPORATION
SECTION ANALYSIS




COMPOSITE OF SECTIONS:

| | | | | |
|---|---|---|---|---|
| | Area= | 10.9375 | | |
| CENTER OF GRAVITY: | Gx= | 0.000 | Gy= | 0.000 |
| INERTIA: | Ix= | 52.9671 | Iy= | 18.2406 |
| PRODUCT OF INERTIA: | Pxy= | 0.0000 | | |
| | Imax= | 52.9671 | Imin= | 18.2406 |
| ANGLE: | 0.00 (Deg) | | | |

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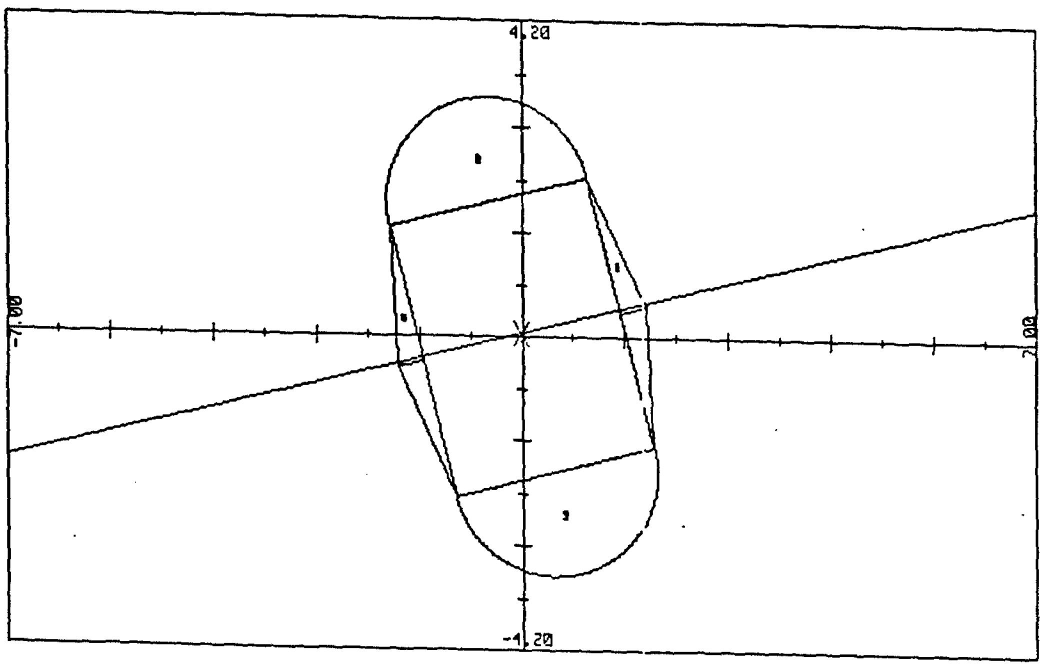
SECTION ANALYSIS




COMPOSITE OF SECTIONS:

| | | | | |
|---|---|---|---|---|
| | Area= | 17.7756 | | |
| CENTER OF GRAVITY: | Gx= | -0.012 | Gy= | 0.047 |
| INERTIA: | Ix= | 48.1413 | Iy= | 14.8243 |
| PRODUCT OF INERTIA: | Pxy= | -8.8441 | | |
| | Imax= | 50.3434 | Imin= | 12.6222 |
| ANGLE: | 13.98 (Deg) | | | |

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HAYES-ALBION CORPORATION
SECTION ANALYSIS

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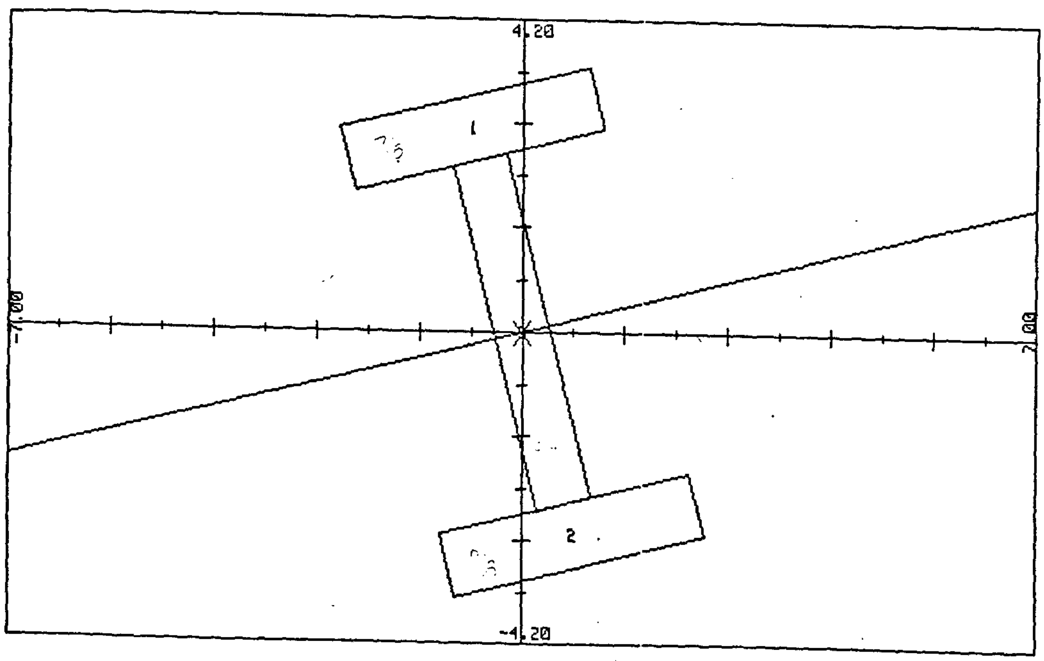
SECTION ANALYSIS




COMPOSITE OF SECTIONS:

| | | | | |
|---|---|---|---|---|
| | Area= | 9.6875 | | |
| CENTER OF GRAVITY: | Gx= | 0.000 | Gy= | -0.000 |
| INERTIA: | Ix= | 52.6658 | Iy= | 9.2921 |
| PRODUCT OF INERTIA: | Pxy= | -11.5255 | | |
| | Imax= | 55.5382 | Imin= | 6.4197 |
| ANGLE: | 13.99 (Deg) | | | |

File Name:

HAYES-ALBION CORPORATION
SECTION ANALYSIS

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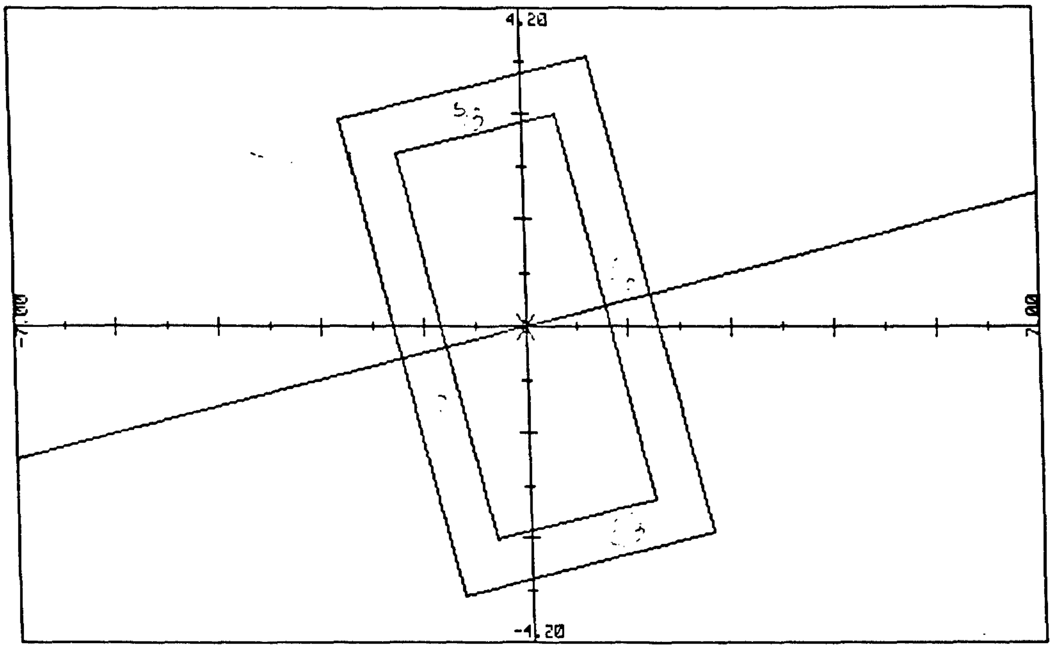


COMPOSITE OF SECTIONS:

| | | | | |
|---|---|---|---|---|
| | Area= | 10.9370 | | |
| CENTER OF GRAVITY: | Gx= | 0.000 | Gy= | 0.000 |
| INERTIA: | Ix= | 50.9334 | Iy= | 20.2716 |
| PRODUCT OF INERTIA: | Pxy= | -8.1491 | | |
| | Imax= | 52.9647 | Imin= | 18.2404 |
| ANGLE: | 14.00 (Deg) | | | |

File Name:

HAYES-ALBION CORPORATION
SECTION ANALYSIS

APPENDIX B

EFFECT OF VARYING QUENCH TEMPERATURE

AND TIME

ON

MECHANICAL PROPERTIES

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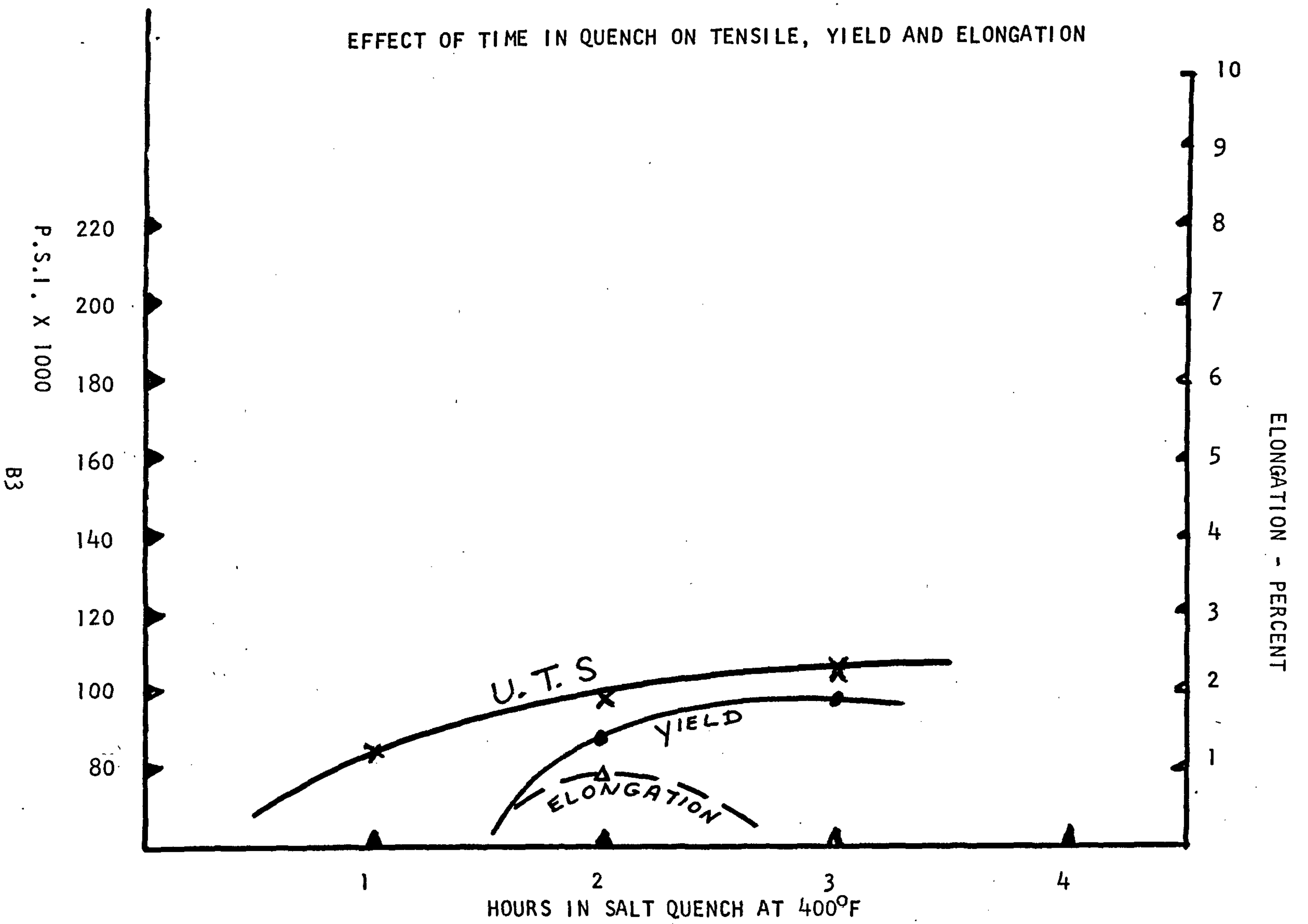
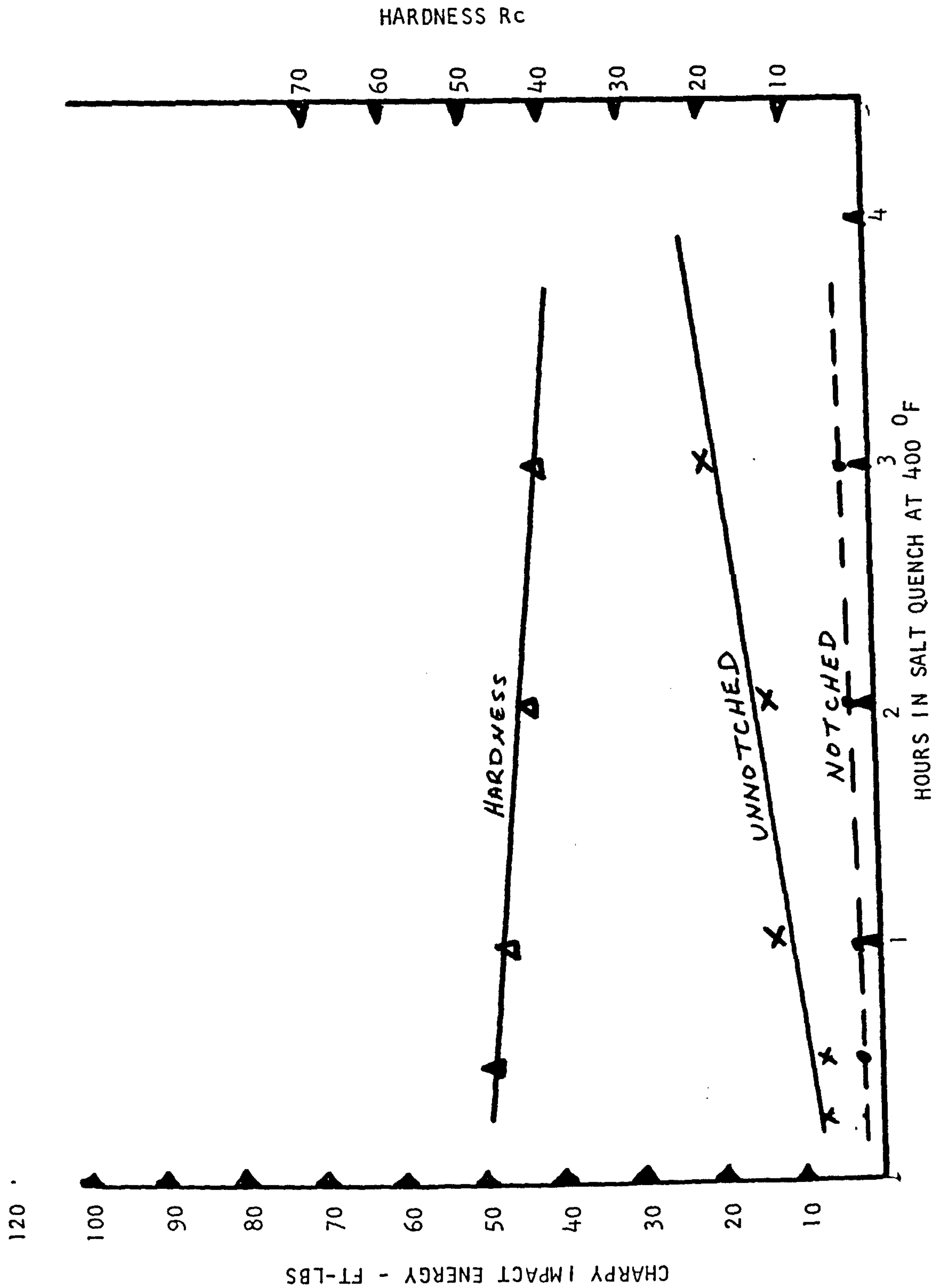
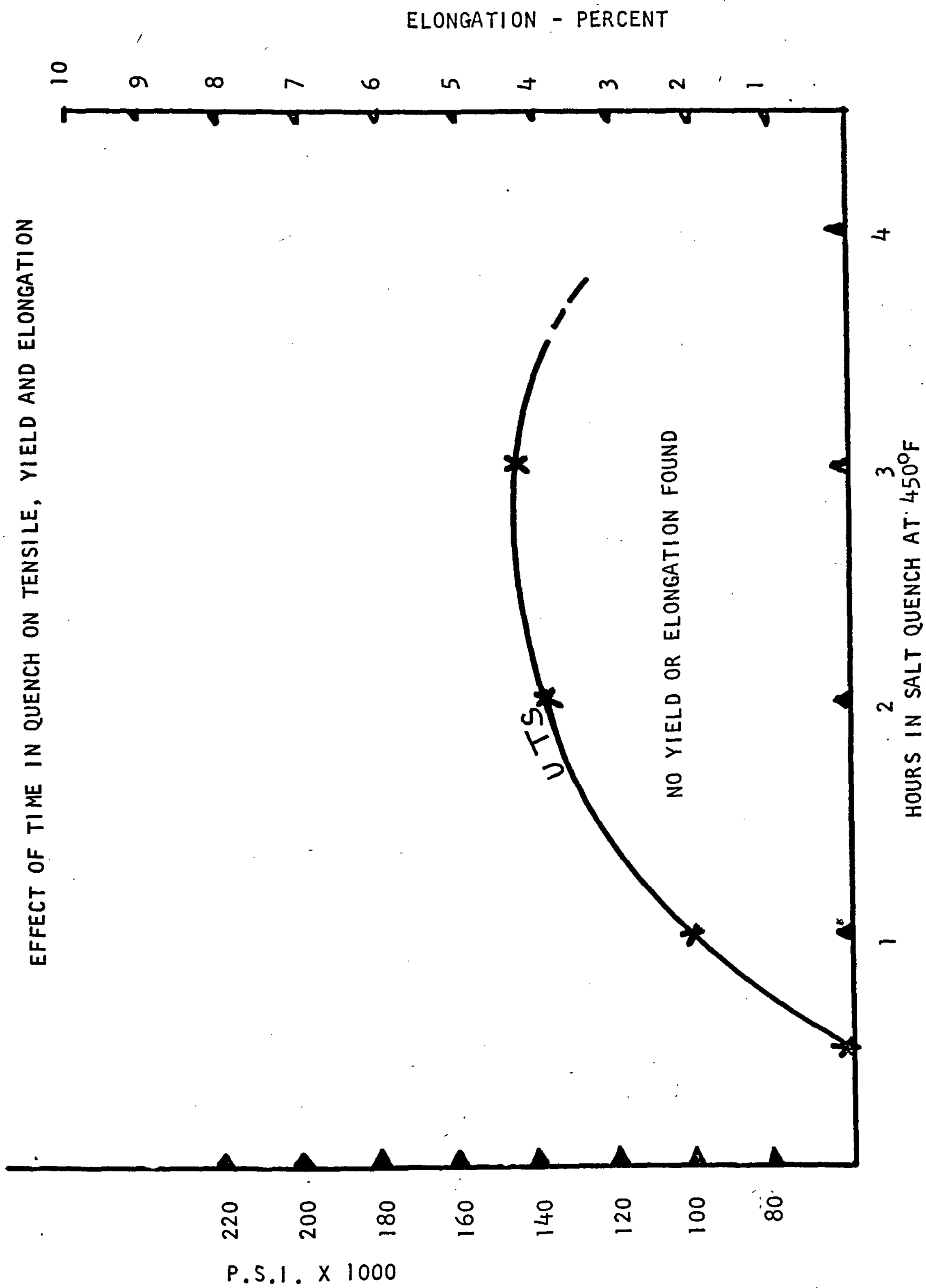

EFFECT OF TIME IN QUENCH ON TENSILE, YIELD AND ELONGATION
P.S.I. X 1000
220
200
180
160
140
120
100
80
ELONGATION - PERCENT
10
9
8
7
6
5
4
3
2
1
U.T.S
YIELD
ELONGATION
1
2
3
4
HOURS IN SALT QUENCH AT 400°F

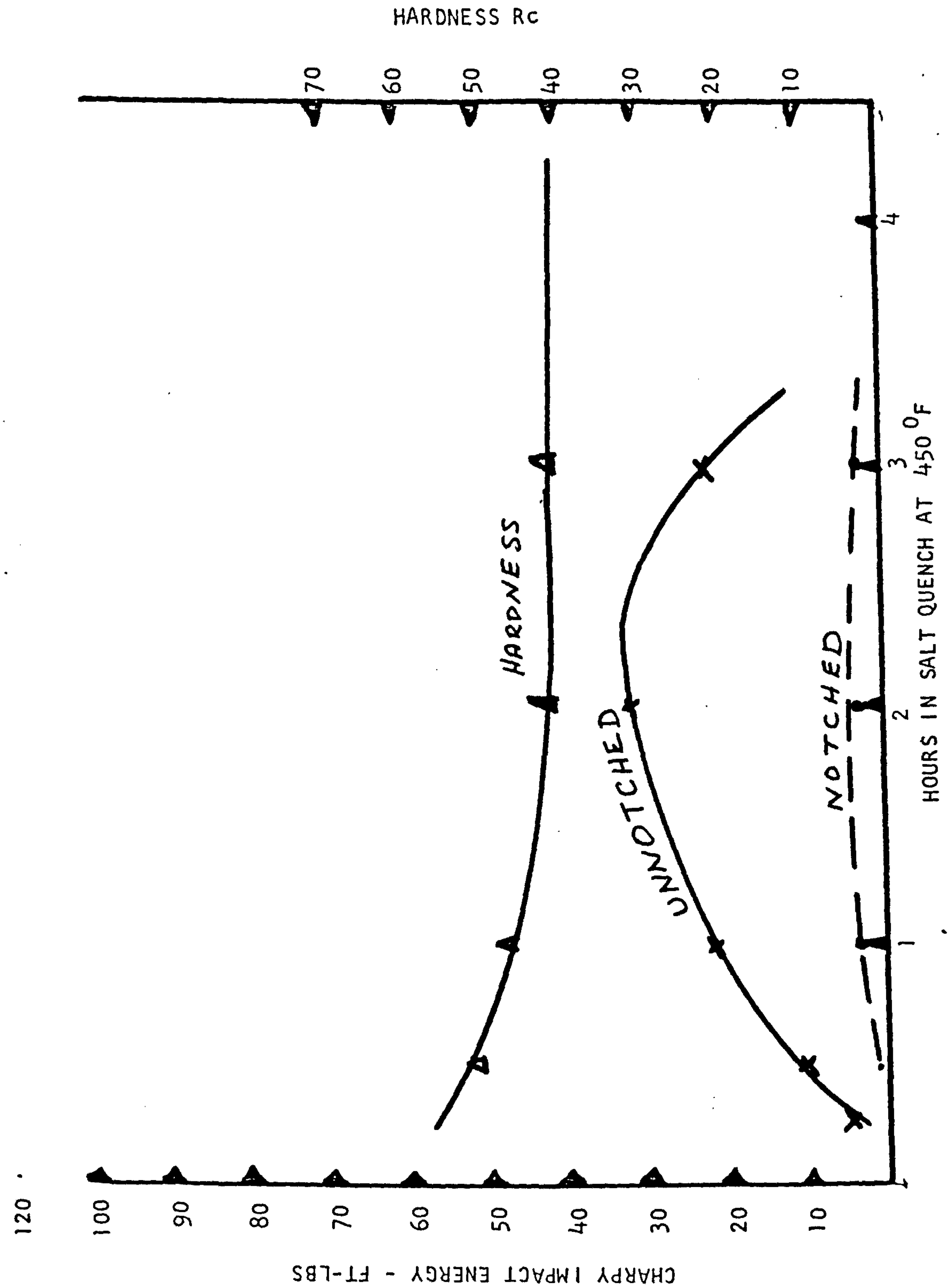
NOTE: Hardness shown is apparent or macro hardness. Actual hardness as measured by Brinnell hardness tester will measure 5 to 7 points harder.




EFFECT OF TIME IN QUENCH ON CHARPY IMPACT - NOTCHED AND UNNOTCHED AND HARDNESS

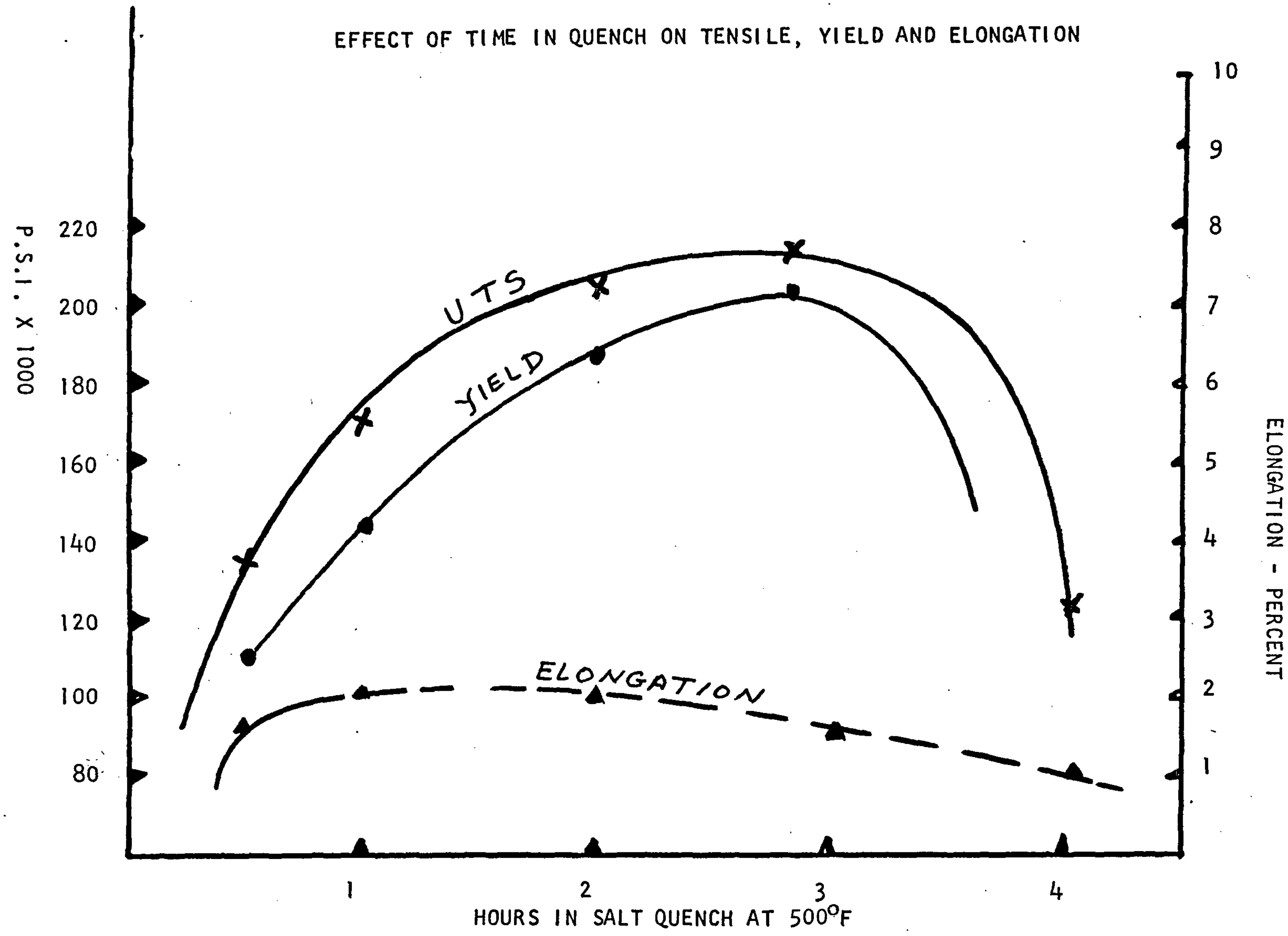

EFFECT OF TIME IN QUENCH ON TENSILE, YIELD AND ELONGATION
ELONGATION - PERCENT
10
9
8
7
6
5
4
3
2
1
UTS
NO YIELD OR ELONGATION FOUND
1
2
3
4
HOURS IN SALT QUENCH AT 450°F
220
200
180
160
140
120
100
80
P.S.I. X 1000

NOTE: Hardness shown is apparent or macro hardness. Actual hardness as measured by Brinnell hardness tester will measure 5 to 7 points harder.

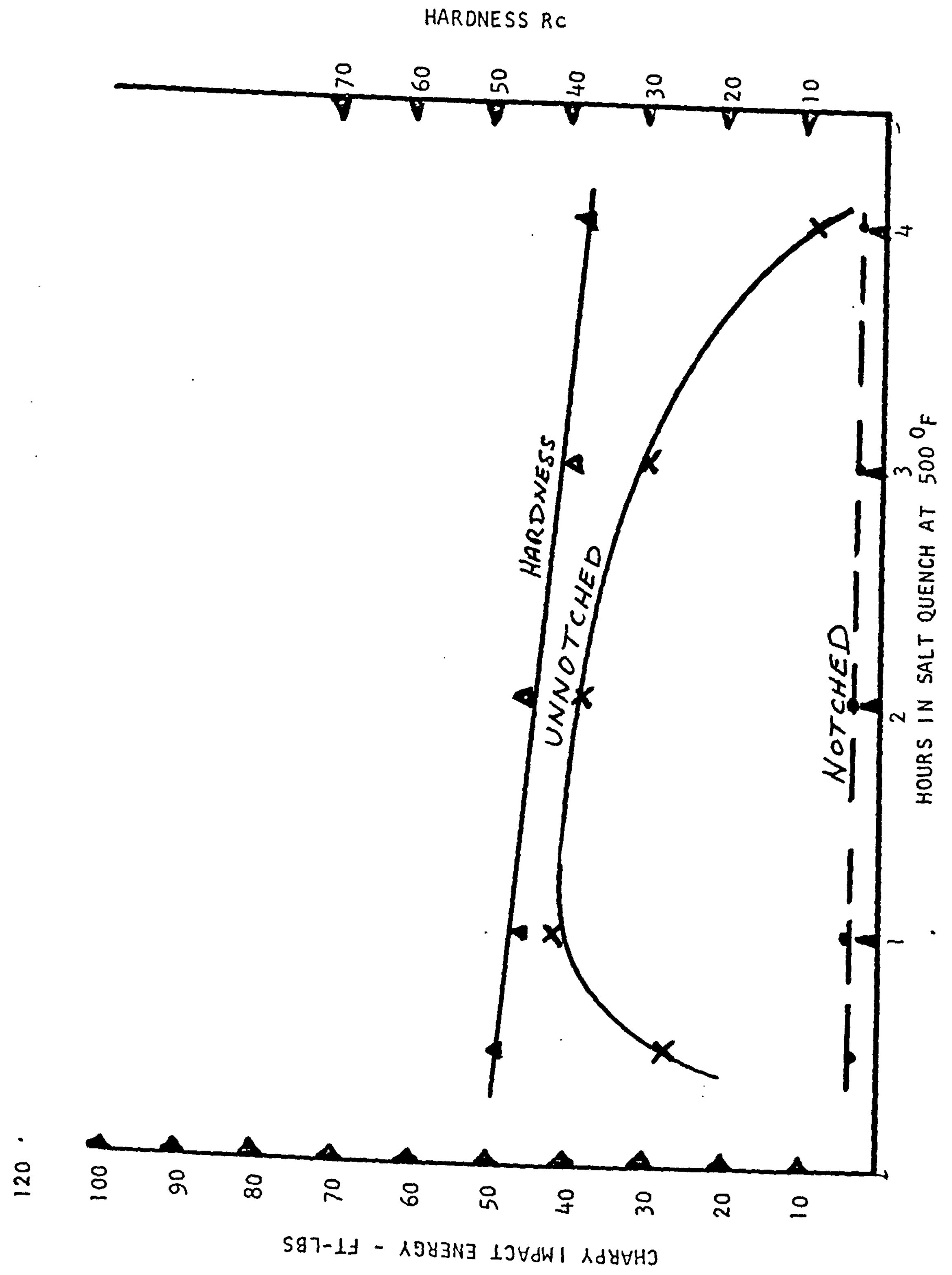



EFFECT OF TIME IN QUENCH ON CHARPY IMPACT - NOTCHED AND UNNOTCHED AND HARDNESS

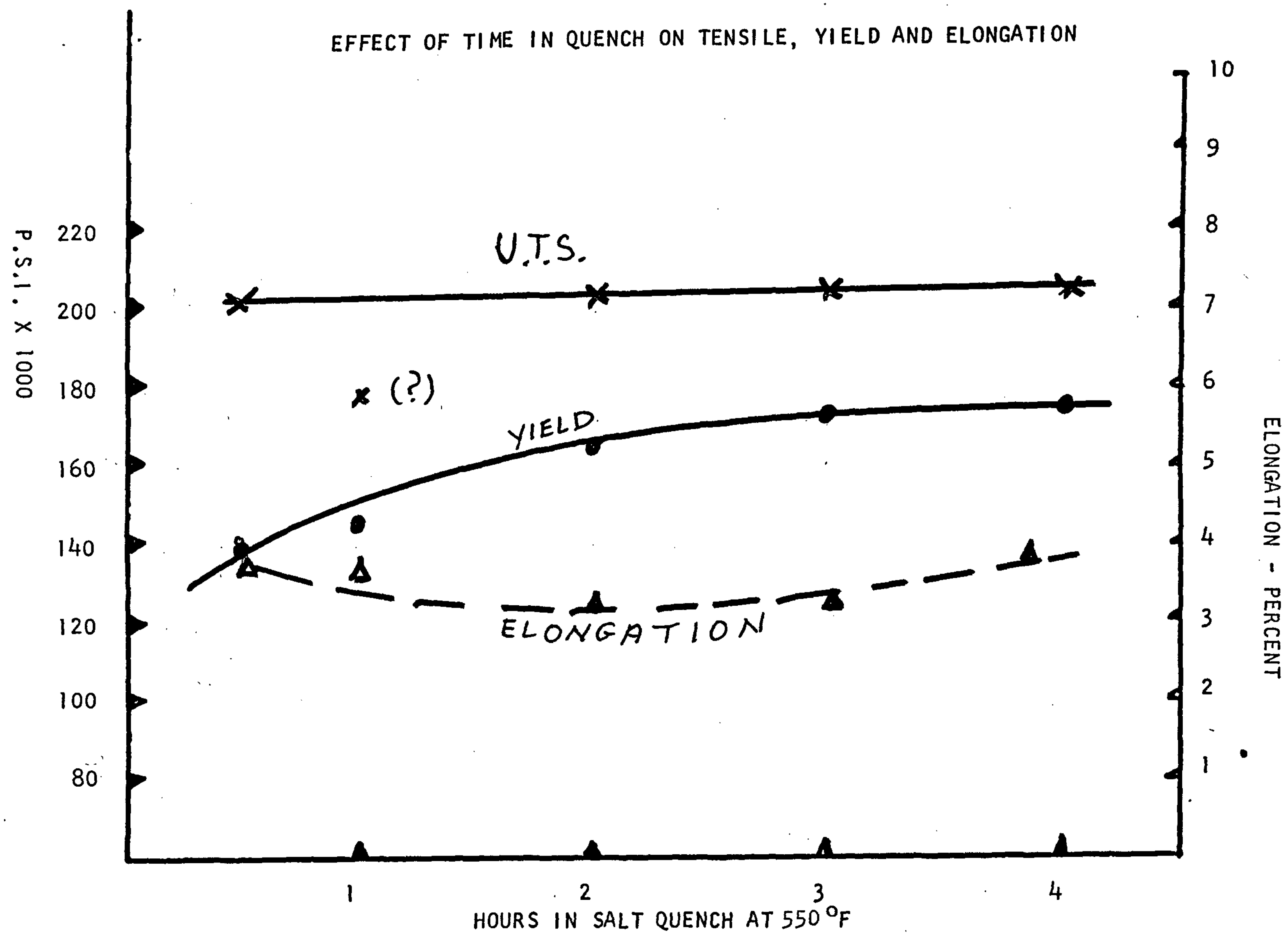
EFFECT OF TIME IN QUENCH ON TENSILE, YIELD AND ELONGATION



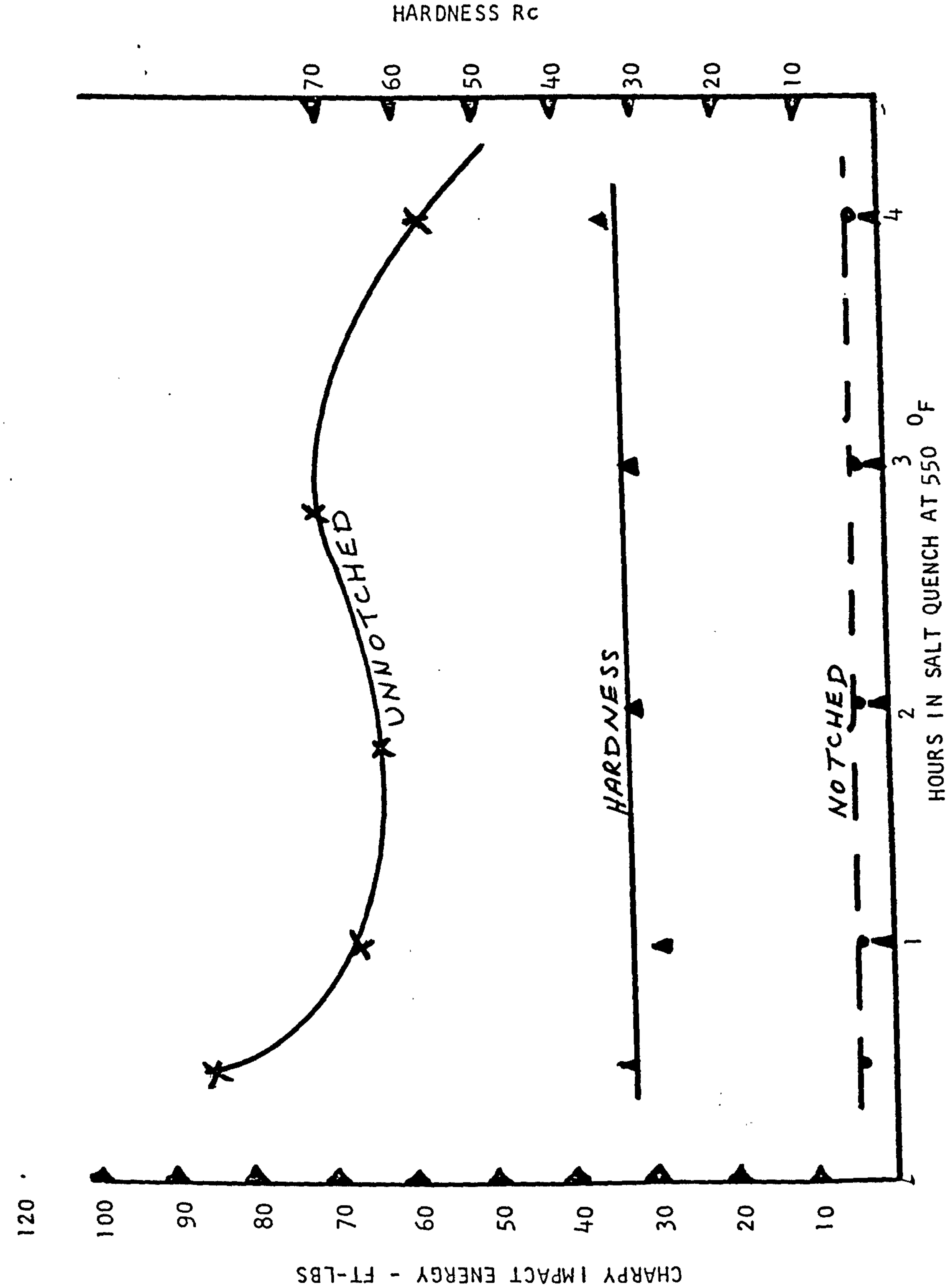
NOTE: Hardness shown is apparent or macro hardness. Actual hardness as measured by Brinnell hardness tester will measure 5 to 7 points harder.




EFFECT OF TIME IN QUENCH ON CHARPY IMPACT - NOTCHED AND UNNOTCHED AND HARDNESS

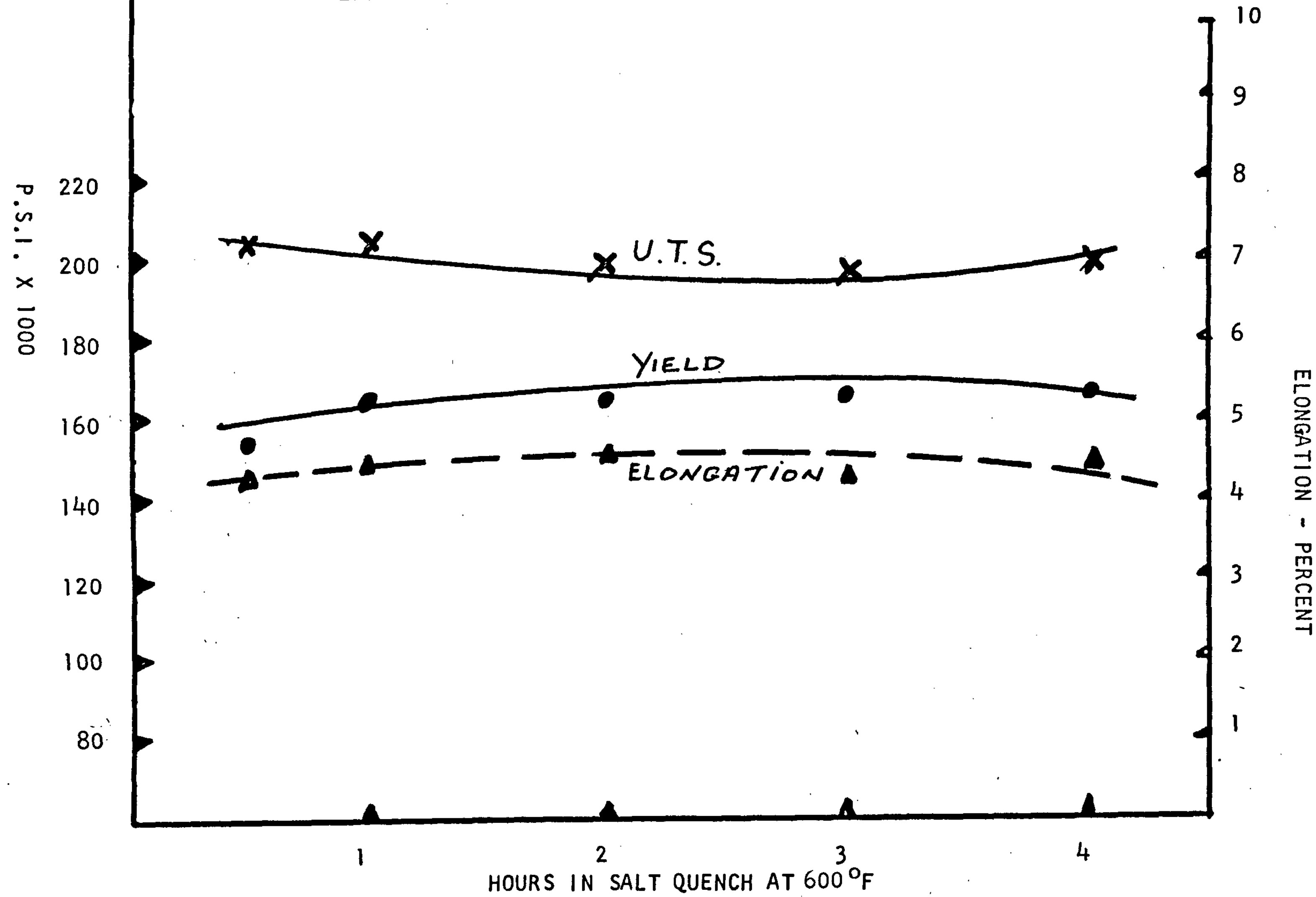

EFFECT OF TIME IN QUENCH ON TENSILE, YIELD AND ELONGATION
U.T.S.
YIELD
ELONGATION
(?)
P.S.I. X 1000
220
200
180
160
140
120
100
80
ELONGATION - PERCENT
10
9
8
7
6
5
4
3
2
1
HOURS IN SALT QUENCH AT 550 °F
1
2
3
4

NOTE: Hardness shown is apparent or macro hardness. Actual hardness as measured by Brinnell hardness tester will measure 5 to 7 points harder.

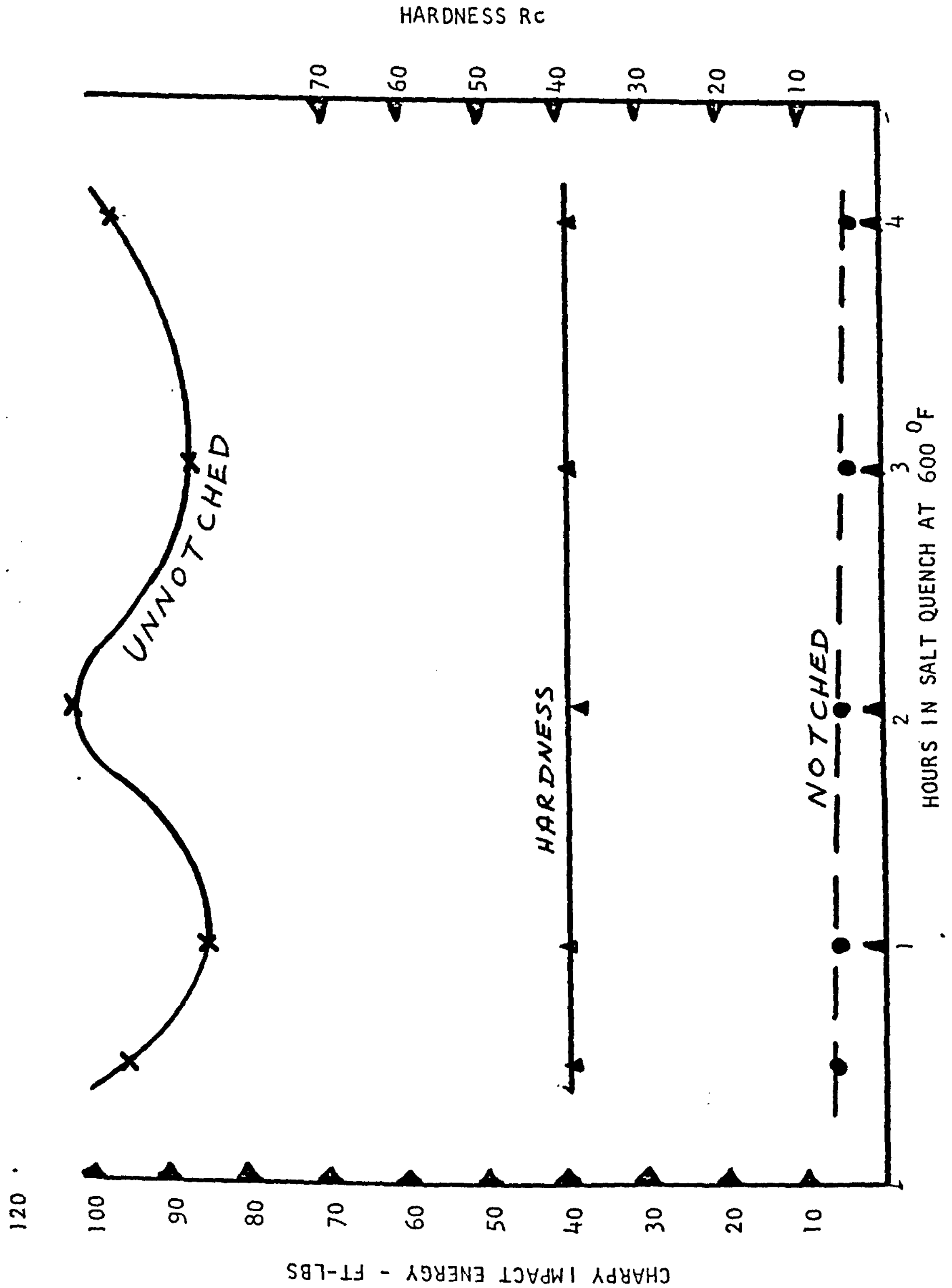



EFFECT OF TIME IN QUENCH ON CHARPY IMPACT - NOTCHED AND UNNOTCHED AND HARDNESS

EFFECT OF TIME IN QUENCH ON TENSILE, YIELD AND ELONGATION

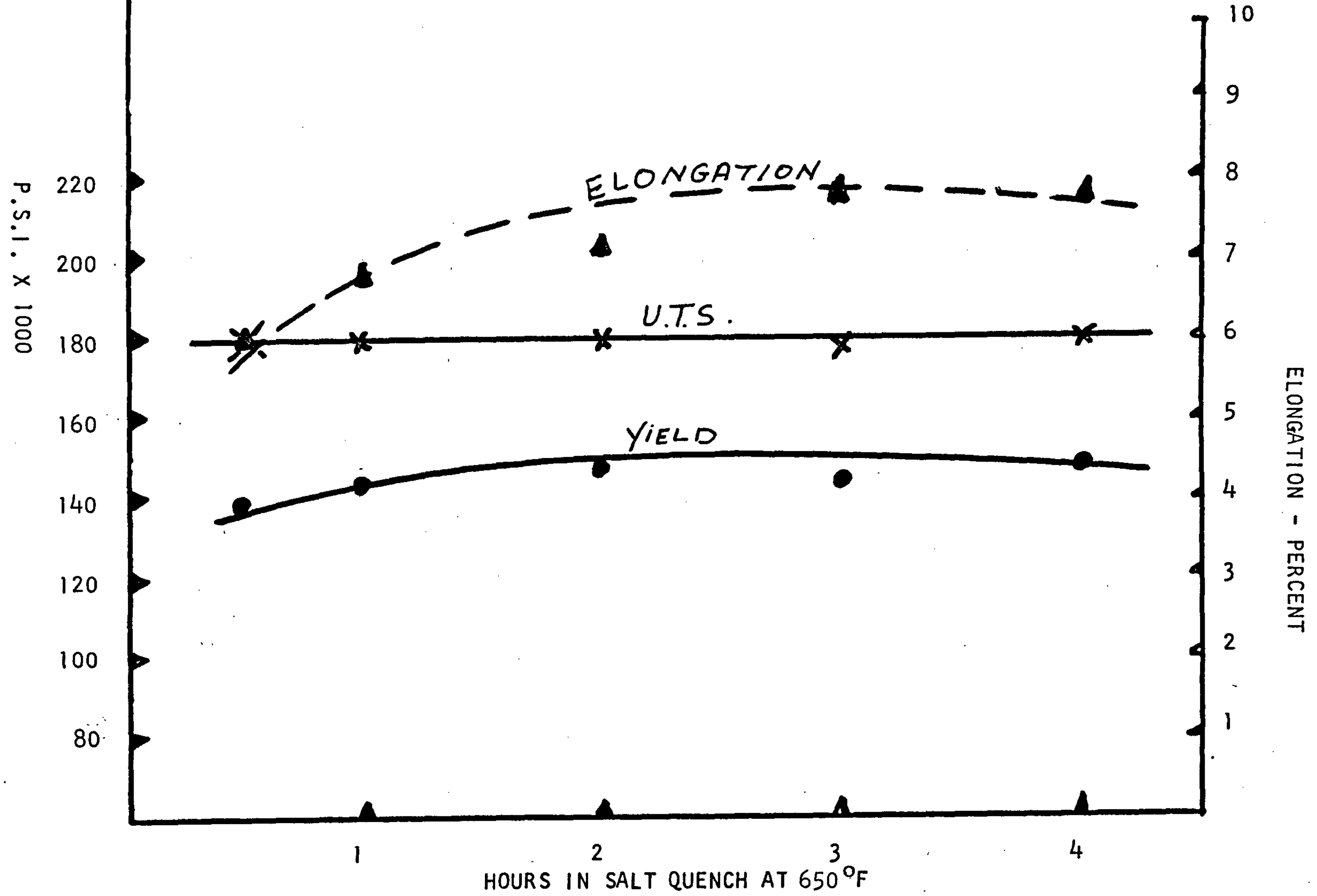


NOTE: Hardness shown is apparent or macro hardness. Actual hardness as measured by Brinnell hardness tester will measure 5 to 7 points harder.

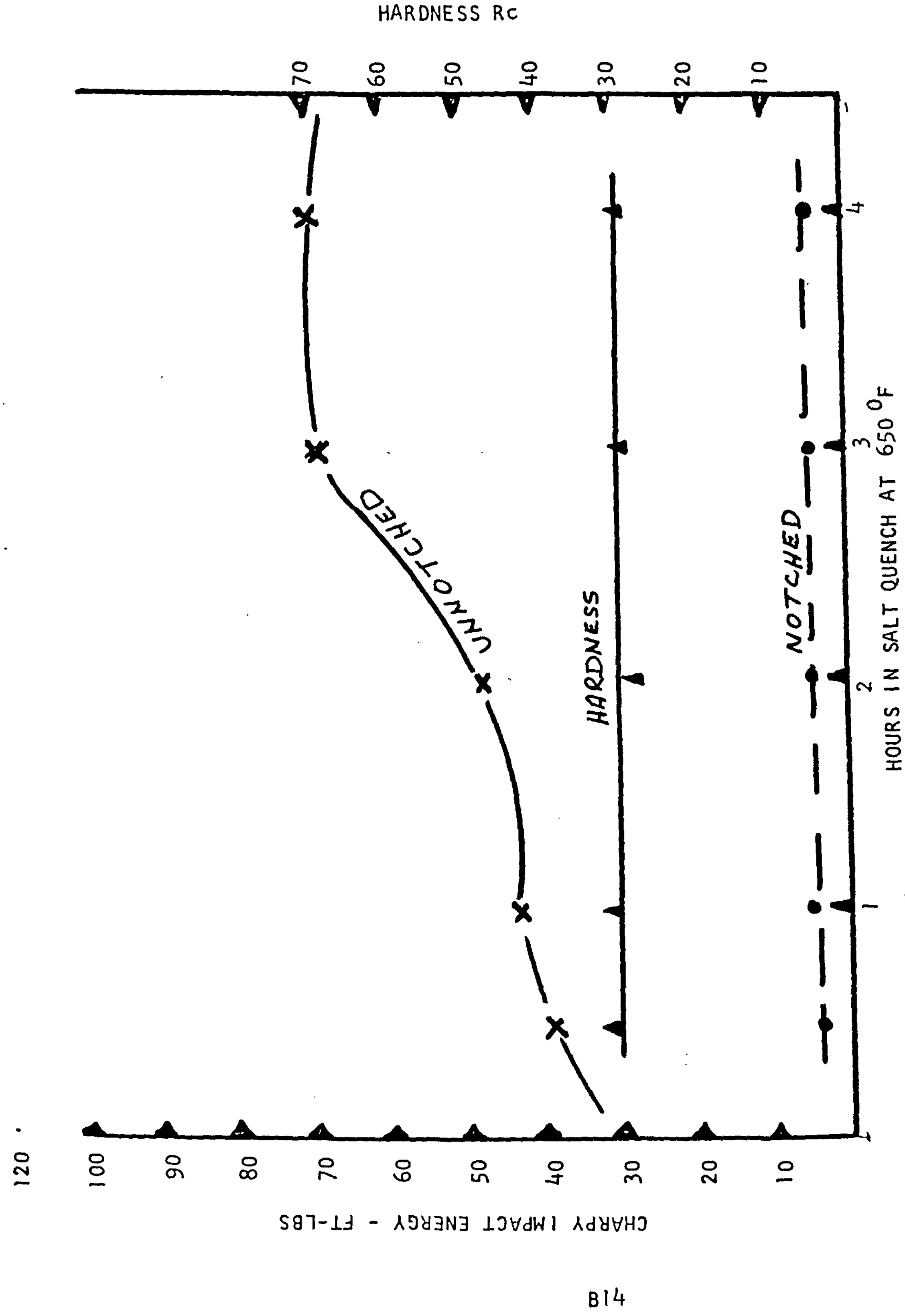



EFFECT OF TIME IN QUENCH ON CHARPY IMPACT - NOTCHED AND UNNOTCHED AND HARDNESS

EFFECT OF TIME IN QUENCH ON TENSILE, YIELD AND ELONGATION

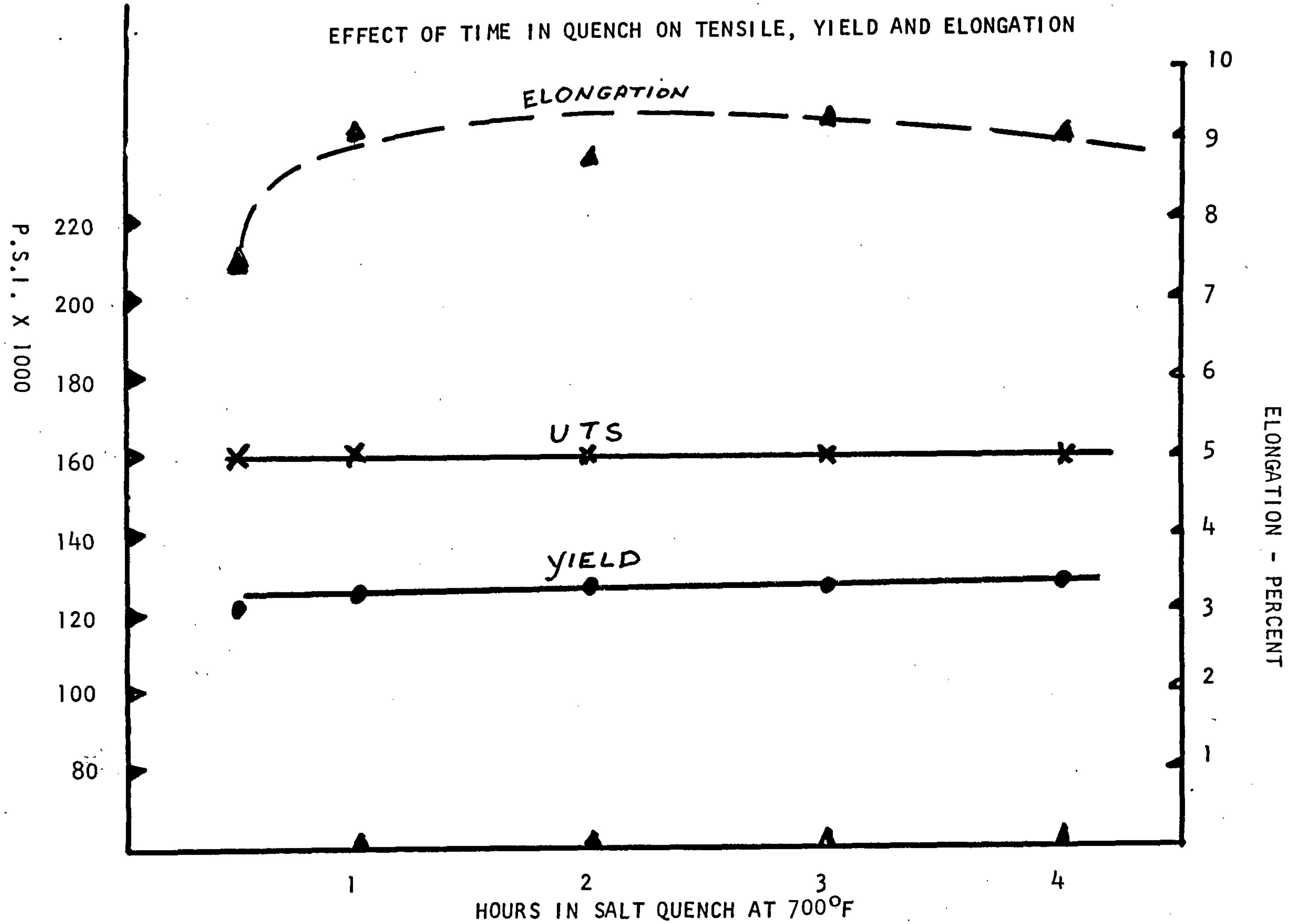


NOTE: Hardness shown is apparent or macro hardness. Actual hardness as measured by Brinnell hardness tester will measure 5 to 7 points harder.

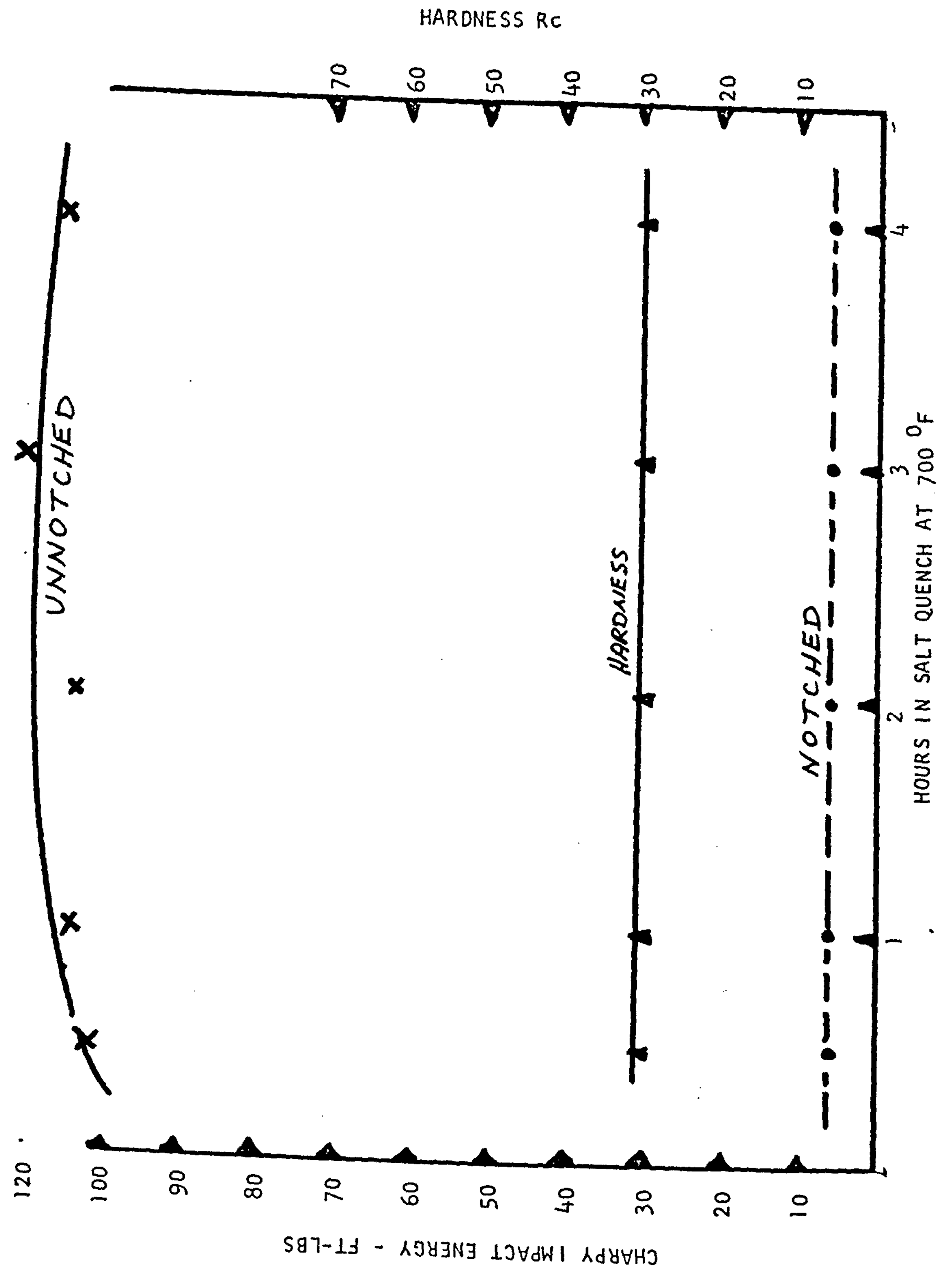



EFFECT OF TIME IN QUENCH ON CHARPY IMPACT - NOTCHED AND UNNOTCHED AND HARDNESS

EFFECT OF TIME IN QUENCH ON TENSILE, YIELD AND ELONGATION

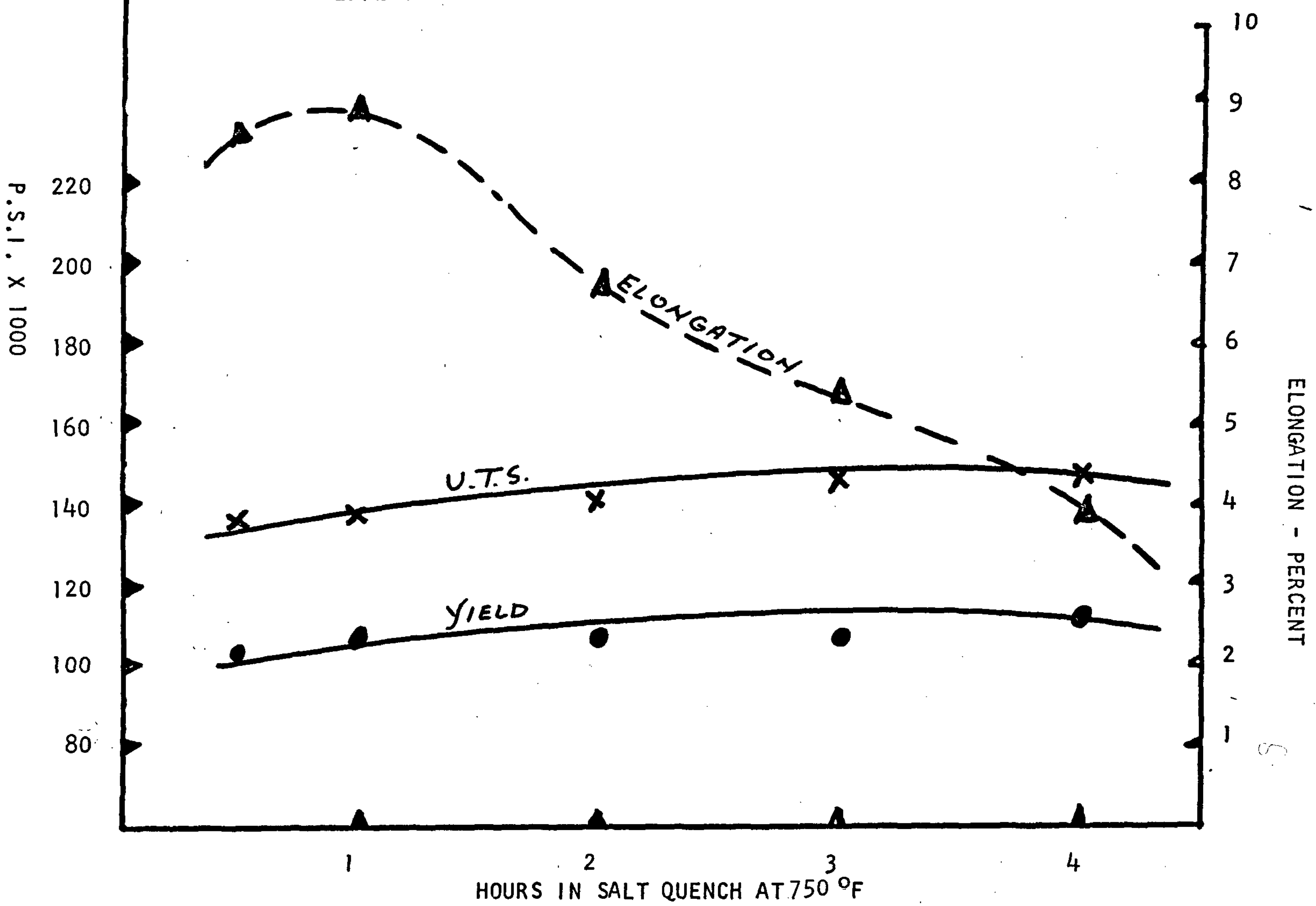


NOTE: Hardness shown is apparent or macro hardness. Actual hardness as measured by Brinnell hardness tester will measure 5 to 7 points harder.

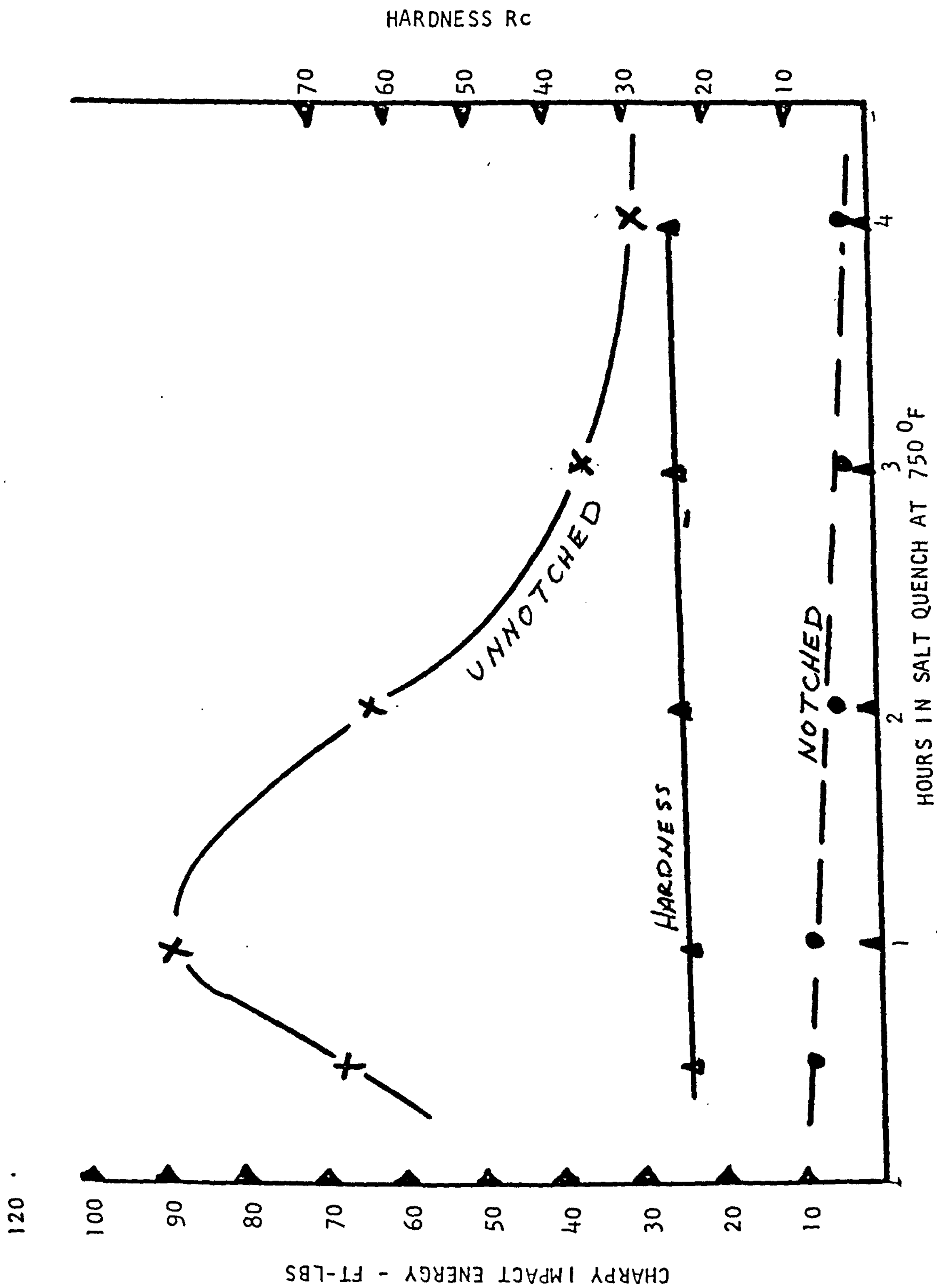



EFFECT OF TIME IN QUENCH ON CHARPY IMPACT - NOTCHED AND UNNOTCHED AND HARDNESS

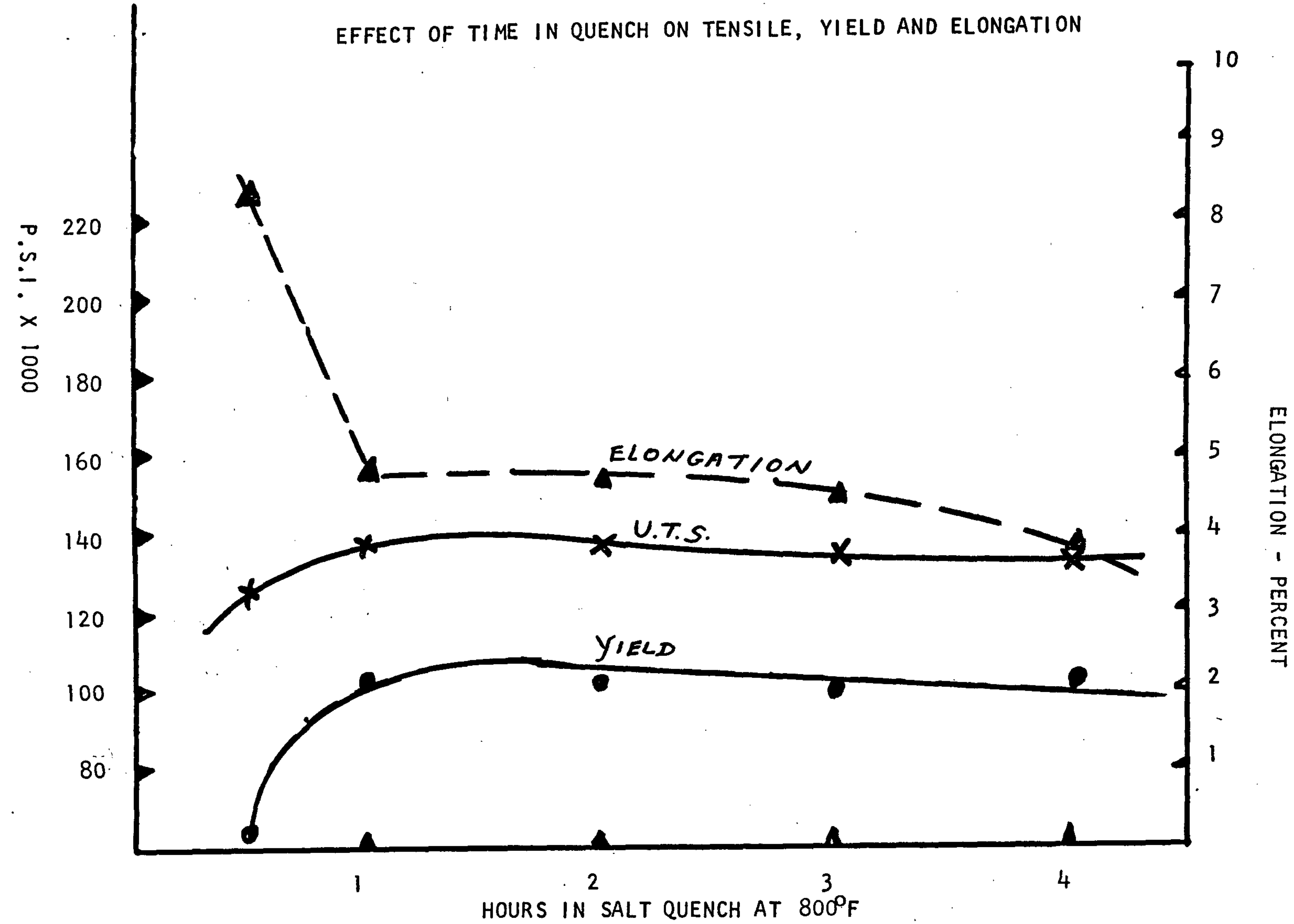
EFFECT OF TIME IN QUENCH ON TENSILE, YIELD AND ELONGATION



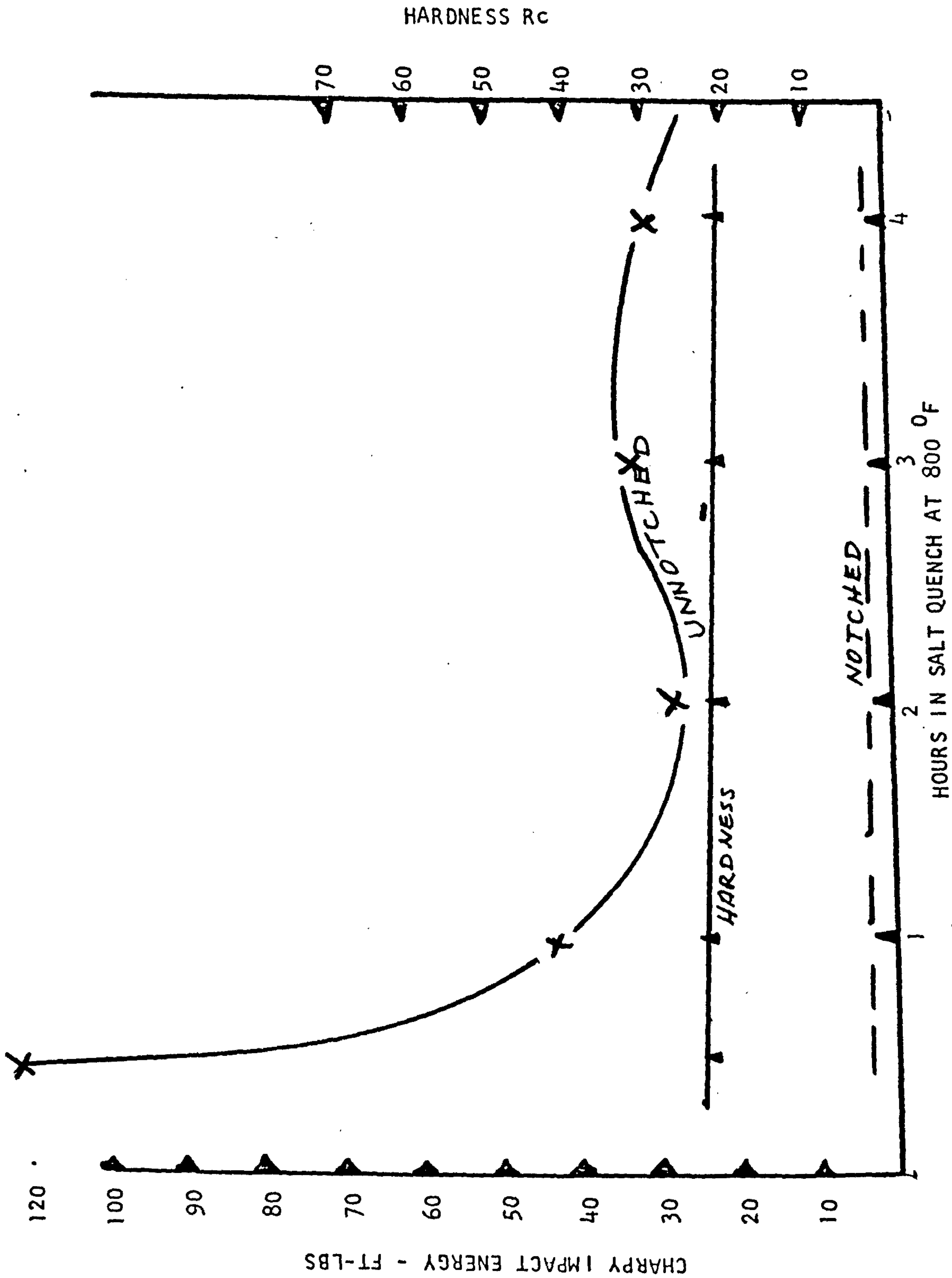
NOTE: Hardness shown is apparent or macro hardness. Actual hardness as measured by Brinnell hardness tester will measure 5 to 7 points harder.




EFFECT OF TIME IN QUENCH ON CHARPY IMPACT - NOTCHED AND UNNOTCHED AND HARDNESS


EFFECT OF TIME IN QUENCH ON TENSILE, YIELD AND ELONGATION
P.S.I. X 1000
220
200
180
160
140
120
100
80
10
9
8
7
6
5
4
3
2
1
ELONGATION - PERCENT
ELONGATION
U.T.S.
YIELD
1
2
3
4
HOURS IN SALT QUENCH AT 800°F

NOTE: Hardness shown is apparent or macro hardness. Actual hardness as measured by Brinnell hardness tester will measure 5 to 7 points harder.




EFFECT OF TIME IN QUENCH ON CHARPY IMPACT - NOTCHED AND UNNOTCHED AND HARDNESS

## BAINITIC DUCTILE IRON PROJECT

| LOT No. | BAR No. | QCH TIME | YIELD ,000 | TENS. ,000 | ELONG. % | Rc Macro | Rc Micro | BHN | N – UN CHARPY Ft Lb | LENGTH INCHES | COMMENT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 400° | 1 | 15MIN | — | | | 51 | | | 4½ - 7 | | BAR CRACKED LENGTHW |
| | 2 | | | | | 48 | | | 2½ - 9 | | " " " |
| | 3 | | | | 49 | 49 | | 9.63 | 2¼ - 5¼ | 6.9 | " " " |
| | 4 | | | | | 48 | | | 2 - 7 | | " " " |
| | 5 | | | | | 49 | | | 2 - 6½ | | BAR BROKE IN THREADS |
| 400° | 1 | 30MIN | | 51 | | 48 | | | 2 - 9 | | |
| | 2 | | | | | 51 | | | 1½ - 5½ | | BROKE IN THREADS |
| | 3 | | | 46 | 49.4 | 48 | | 1.7 | 1¾ - 6¼ | 6.9 | |
| | 4 | | | | | 51 | | | 1¼ - 6¼ | | BROKE IN THREADS |
| | 5 | | | 51 | | 49 | | | 2 - 7½ | | |
| 400° | 1 | 1HRS | | 84 | | 45 | | | — - 14 | | |
| | 2 | | | 77 | | 50 | | | 2 - 16¼ | | |
| | 3 | | | 79 | 47.4 | 48 | | 2 | 1¾ - 12½ | 14.2 | |
| | 4 | | | 89 | | 48 | | | 2¼ - 12¼ | | |
| | 5 | | | 88 | | 46 | | | 2 - 35¼ | 14 | CHARPY BAR DODGED IN MK |
| 400° | 1 | 2HRS | | 83 | | 45 | | | 2½ - 14 | | |
| | 2 | | 93 | 96 | 1.0 | 46 | | | 2¾ - 14¾ | | |
| | 3 | | 93 | 105 97.4 | 1.0 | 44 | 44.6 | 2.35 | 2¼ - 12½ | 14.75 | |
| | 4 | | 84 88 | 112 | .5 | 44 | | | 2¼ - 12 | | |
| | 5 | | 82 | 91 | | 44 | | | 3 - 20½ | | |
| 400° | 1 | 3HRS | 88 | 102 | | 43 | | | 2½ - 9 | | DEFECT CHARPY |
| | 2 | | 92 | 92 105 | | 40 | | 3.2 | 3¼ - 14 | | |
| | 3 | | 101 97.2 | 115 | | 44 | 41.4 | | 4 - 26¾ | 21.16 | |
| | 4 | | 101 | 105 | | 39 | | | 3¼ - 8½ | | DEFECT CHARPY |
| | 5 | | 104 | 111 | | 41 | | | 3 - 22¾ | | |

## BAINITIC DUCTILE IRON PROJECT

| LOT No. | BAR No. | QCH TIME | YIELD ,000 | TENS. ,000 | ELONG. % | Rc Macro | Rc Micro | BHN | W-UNN CHARPY Ft Lb | LENGTH INCHES | COMMENT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 450° | 1 | 15MIN. | — | 33 | | 51 | | | 3/4 - 4 1/4 | | THIS ENTIRE LOT |
| | 2 | | | 35 | 33.3 | 48 | | | 3/4 - 3 3/4 | | HAD EXCESSIVE |
| | 3 | | | — | | 52 | 50 | .75 | 1 - 6 1/4 | 5.06 | SCALE. |
| | 4 | | | 35 | | 48 | | | 3/4 - 6 | | |
| | 5 | | | — | | 51 | | | 1/2 - — | | DEFECTIVE CHARPY |
| 450° | 1 | 30MIN | | 76 | | 53 | | | 1 - 10 1/2 | | |
| | 2 | | | 67 | 70.25 | 53 | | | 2 - 10 1/4 | | |
| | 3 | | | 65 | | 51 | 52.6 | | 2 1/2 - 9 3/4 | 10.2 | |
| | 4 | | | 73 | | 53 | | 1.63 | 1 1/2 - 10 1/4 | | |
| | 5 | | | — | | 53 | | | 1 1/4 - ~~2 1/4~~ | | DEFECTIVE CHARPY |
| 450° | 1 | 1HR. | | 104 | | 47 | | | 2 3/4 - 22 1/2 | | |
| | 2 | | | 101 | | 47 | | | 4 1/2 - 22 1/4 | | |
| | 3 | | | 104 | 99.6 | 50 | 47.8 | | — ~~15 3/4~~ | | CHARPY BAR JAMMED IN MACHINE |
| | 4 | | | 94 | | 49 | | 3.6 | ~~3 1/2~~ - 22 1/2 | 22.31 | DEFECTIVE CHARPY |
| | 5 | | | 95 | | 46 | | | 3 1/2 - 22 | | |
| 450° | 1 | 2HRS | | 141 | | 45 | | | 3 1/2 - ~~18 1/2~~ | | DEFECTIVE CHARPY |
| | 2 | | | 139 | | 41 | | | 4 1/4 - 38 1/4 | | |
| | 3 | | | 144 | 137.6 | 44 | 44 | 3.8 | 4 1/4 - 31 1/4 | 32.6 | |
| | 4 | | | 124 | | 44 | | | ~~2 3/4~~ - 38 1/4 | | |
| | 5 | | | 140 | | 46 | | | 3 1/4 - ~~10 1/4~~ | | DEFECTIVE CHARPY |
| 450° | 1 | 3HRS | | 154 | | 41 | | | 3 3/4 - ~~8 1/4~~ | | DEFECTIVE CHARPY |
| | 2 | | | 126 | | 44 | | | — - 21 | | CHARPY BAR JAMMED IN MACH. |
| | 3 | | | 149 | 142.2 | 44 | 44.4 | 3.16 | — - 22 1/2 | 22.25 | " " " |
| | 4 | | | 140 | | 47 | | | 2 3/4 - 22 1/2 | | |
| | 5 | | | 142 | | 46 | | | 3 - 23 | | |

BAINITIC DUCTILE IRON PROJECT

| LOT No. | BAR No. | QCH TIME | YIELD ,000 | TENS. ,000 | ELONG. % | Rc Macro | Rc Micro | BHN | N- UNN CHARPY Ft Lb | LENGTH INCHES | COMMENT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 500° | 1 | 30 MIN | 110 | 126 | 1.5 | 45 | | | 3 - 23½ | | |
| | 2 | | 110 | 122 | 1.0 | 48 | | | 3¾ - 17½ | | DEFECTIVE CHARPY |
| | 3 | | 112 | 124 | 1.5 | 49 | | 3.25 | 3¾ - 33¼ | 27.56 | |
| | 4 | | 111 | 158 | 2.0 | 49 | | | 3¼ - 23 | | |
| | 5 | | 109 | 152 | 2.0 | 50 | | | 2½ - 30½ | | |
| | | | 110.4 | 136.4 | 1.6 | 48.2 | | | | | |
| 500° | 1 | 1 HR | 155 | 164 | 2.0 | 44 | | | 3 - 43 | | DOUBLE HIT CHARPY |
| | 2 | | — | 148 | 2.5 | 47 | | | 3¼ - 46¾ | 41.875 | |
| | 3 | | 163 | 183 | 2.0 | 45 | | 3 | 3 - 37 | | |
| | 4 | | 152 | 169 | 2.0 | 46 | | | 3 - 11½ | | DEFECTIVE CHARPY |
| | 5 | | 149 | 186 | 2.0 | 46 | | | 2¾ - 14¾ | | DEFECTIVE CHARPY |
| | | | 144.75 | 170.4 | | 45.6 | | | | | |
| 500° | 1 | 2 HRS | 188 | 202 | 2.5 | 47 | | | 3 - 32¼ | | CHARPY JAMMED INITIALLY |
| | 2 | | 186 | 203 | 2.0 | 44 | | | — - 38½ | | |
| | 3 | | 194 | 202 | 1.0 | 46 | | 3.06 | 2¾ - 42¼ | 38 | DID NOT BREAK 1st TIME |
| | 4 | | 185 | 208 | 2.0 | 46 | | | 2¾ - 29¾ | | |
| | 5 | | 184 | 203 | 2.0 | 45 | | | 3¾ - 39 | | |
| | | | 187 | 203.6 | | 45.6 | | | | | |
| 500° | 1 | 3 HRS | 199 | 222 | 2.0 | 42 | | | 3¼ - 30 | | |
| | 2 | | — | 202 | 1.5 | 43 | | | 3 - 14 | | |
| | 3 | | 205 | 215 | 1.5 | 41 | | 2.85 | 2¾ - 38¾ | 30 | |
| | 4 | | 200 | 202 | 1.5 | 34 | | | 2½ - 39¾ | | |
| | 5 | | 203 | 221 | 1.5 | 36 | | | 2¾ - 28 | | |
| | | | 201.75 | 212.4 | | 39.6 | | | | | |
| 500° | 1 | 4 HRS | — | 108 | 1.0 | 38 | | | 2¼ - 8¼ | | DEFECTIVE CHARPY |
| | 2 | | — | — | — | 41 | | | 2¼ - 9⅛ | | TENSILE BROKE IN THREADS |
| | 3 | | — | 137 | 1.0 | 35 | | | 2 - 12¼ | 9.25 | |
| | 4 | | — | 129 | 1.0 | 43 | | | 1¾ - 8¼ | | DEFECTIVE CHARPY |
| | 5 | | — | 121 | 1.0 | 41 | | | 1¾ - 8½ | | DEFECTIVE CHARPY |
| | | | | 123.76 | | 39.6 | | | | | |

BAINITIC DUCTILE IRON PROJECT

| LOT No. | BAR No. | QCH TIME | YIELD ,000 | TENS. ,000 | ELONG. % | Rc Macro | Rc Micro | BHN | N- UNN CHARPY Ft Lb | LENGTH INCHES | COMMENT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 550° | 1 | 30 MIN. | 135 | 203 | 4.0 | 36 | | | 5 -76 | | |
| $H_2O$ IN SALT | 2 | | 139 | 204 | 4.0 | 36 | | | 4¼-85½ | | |
| | 3 | | 140 | 197 | 4.0 | 32 | | | 3½-95½ | | |
| | 4 | | 148 | 210 | 4.0 | 36 | | | (33) | | DEFECT CHARPY |
| | 5 | | 136 | 200 | 3.5 | 30 | | | 4.75 -85½ | 85.37 | |
| | | | 139.6 | 202.9 | 3.9 | 34 | | | | | |
| 550° | 1 | 1 HR. | 165 | 192 | 3.0 | 33 | | | 3¾-56 | | |
| $H_2O$ IN SALT | 2 | | 158 | 193 | 4.0 | 38 | | | 3½-71 | | |
| | 3 | | 135 | 173 | 4.0 | 25 | | | 5½-(60) | | DEFECT CHARPY |
| | 4 | | 116 | 152 | 3.5 | 25 | | | 4.75-81½ | | |
| | 5 | | 151 | 188 | 3.5 | 20 | 28 | | (55) | 66 | DEFECT CHARPY |
| | | | 145 | 179.6 | 3.6 | | | | | | |
| 550° | 1 | 2 HRS | 168 | 202 | 2.5 | 30 | | | 4¼-63 | | |
| $H_2O$ IN SALT | 2 | | 168 | 206 | 3.0 | 30 | | | 4 -65 | | |
| | 3 | | 170 | 205 | 3.5 | 36 | | | 4¾-(33) | | DEFECT CHARPY |
| | 4 | | 154 | 186 | 3.5 | 31 | | | 3¾-(18½) | | DEFECT CHARPY |
| | 5 | | 168 | 209 | 3.5 | 36 | 32.6 | | 4 -66 | 64.6 | |
| | | | 165.6 | 201. | 3.2 | | | | | | |
| 550° | 1 | 3 HRS | 176 | 211 | 4.0 | 32 | | | 4½-86 | | |
| $H_2O$ IN SALT | 2 | | 174 | 187 | 1.5 | 34 | | | 4 -86 | | DEFECT. TENSILE |
| | 3 | | 171 | 197 | 2.0 | 31 | | | 4¼-65 | | |
| | 4 | | 169 | 206 | 4.5 | 33 | | | 4¾-70½ | | |
| | 5 | | 168 | 204 | 4.5 | 35 | 33 | | 4.375 53¼ | 72.6 | |
| | | | 171.6 | 201 | 3.3 | | | | | | |
| 550° | 1 | 4 HRS | 177 | 208 | 4.0 | 37 | | | 5¼-53 | | |
| $H_2O$ IN SALT | 2 | | 180 | 209 | 4.0 | 34 | | | 4½-52 | | |
| | 3 | | 165 | 195 | 4.0 | 34 | | | 5 -83 | | |
| | 4 | | 178 | 207 | 3.0 | 37 | | | 4½-41 | 57.75 | |
| | 5 | | 170 | 199 | 4.5 | 36 | | | 4.8 -(14½) | | DEFECT CHARPY |
| | | | 174 | 203. | 3.9 | 35.6 | | | | | |

BAINITIC DUCTILE IRON PROJECT

| LOT No. | BAR No. | QCH TIME | YIELD ,000 | TENS. ,000 | ELONG. % | Rc Macro | Rc Micro | BHN | [illegible] CHARPY Ft Lb | LENGTH INCHES | COMMENT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 600° | 1 | 30min | 153 | 205 | 4.0 | 41 | | | 5¼-110 | | |
| ~~Reco~~ | 2 | | 161 | 206 | 4.0 | 41 | | | 5½-79 | | |
| Confirm | 3 | | 150 | 199 | 4.5 | 37 | | | 5½-98.5 | | |
| | 4 | | 157 | 204 | 4.0 | 40 | | | 5.5-95 | | |
| | 5 | | 157 | 206 | 5.0 | 40 | | | | | |
| | | | 155 | 204 | 4.3 | 39.8 | | | | | |
| 600° | 1 | 1HR. | 164 | 204 | 4.0 | 40 | | | 5¾-105 | | |
| ~~Reco~~ | 2 | | 170 | 204 | 5.0 | 39 | | | 5¾-~~37~~ | | |
| Confirm | 3 | | 165 | 204 | 4.5 | 40 | | | 4¾-67½ | | |
| | 4 | | 166 | 202 | 5.0 | 40 | | | 5.4-86 | | |
| | 5 | | 162 | 202 | 4.5 | 38 | | | | | |
| | | | 167 | 203 | | 39.4 | | | | | |
| 600° | 1 | 2HRS | 168 | 204 | 5.0 | 39 | | | 5-89 | | |
| ~~Reco~~ | 2 | | 163 | 196 | 4.0 | 35 | | | 5½-102 | | |
| Confirm | 3 | | 169 | 203 | 4.0 | 38 | | | 5¼-115½ | | |
| | 4 | | 165 | 198 | 4.5 | 39 | | | 5¼-102 | | |
| | 5 | | 168 | 203 | 5.0 | 40 | | | | | |
| | | | 166.6 | 200 | 4.6 | 38.2 | | | | | |
| 600° | 1 | 3HRS. | 166 | 194 | 3.5 | 36 | | | 4½-98 | | |
| ~~Reco~~ | 2 | | 166 | 195 | 4.5 | 39 | | | 4¾-74 | | |
| Confirm | 3 | | 170 | 203 | 4.0 | 39 | | | 4½-90 | | |
| | 4 | | 173 | 203 | 4.5 | 38 | | | 4.6-87 | | |
| | 5 | | 165 | 197 | 4.5 | 38 | | | | | |
| | | | 168 | 198 | 4.2 | 38 | | | | | |
| 600° | 1 | 4HRS. | 165 | 199 | 4.0 | 39 | | | 4-115½ | | |
| ~~Reco~~ | 2 | | 173 | 203 | 4.0 | 39 | | | 4¾-79 | | |
| Confirm | 3 | | 169 | 203 | 5.0 | 39 | | | 4-84 | | |
| | 4 | | 168 | 201 | 5.0 | 39 | | | 4.5-92 | | |
| | 5 | | 165 | 198 | 4.5 | 38 | | | | | |
| | | | 168 | 200 | 4.5 | 39 | | | | | |

## BAINITIC DUCTILE IRON PROJECT

| LOT No. | BAR No. | QCH TIME | YIELD ,000 | TENS. ,000 | ELONG. % | Rc Macro | Rc Micro | BHN | N- UN-N CHARPY Ft Lb | LENGTH INCHES | COMMENT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 650° | 1 | 30 MIN | 142 | 183 | 6.0 | 33 | | | 5 -34½ | | |
| | 2 | | 140 | 178 | 5.0 | 32 | | | 4½-44½ | | |
| | 3 | | 137 | 181 | 5.5 | 34 | 32 | | 3½-36½ | 40.3 | |
| | 4 | | 133 | 179 | 7.0 | 27 | | | 4½-54½ | | |
| | 5 | | 138 | 181 | 6.0 | 34 | | | 5 -31½ | | |
| 650° | | 1 HR | | | | | | | | | |
| | 1 | | 146 | 180 | 6.0 | 32 | | | 5 -50½ | | |
| | 2 | | 143 | 178 | 7.0 | 32 | | | 3½-32 | | |
| | 3 | | 145 | 180 | 7.0 | 29 | 31 | 5.0 | 5½-39¼ | 44.63 | |
| | 4 | | 142 | 179 | 7.0 | 31 | | | 5½-35 | | |
| | 5 | | — | 180 | 7.0 | 31 | | | 5½-66½ | | |
| 650° | 1 | 2 HRS. | 158 | 181 | 7.0 | 31 | | | 5½-~~18~~ | | DEFECT CHARPY |
| | 2 | | 146 | 178 | 7.0 | 24 | | | 6 -26½ | | |
| | 3 | | 145 | 179 | 7.0 | 27 | 28.6 | 5.6 | 5½-32 | 48.2 | |
| | 4 | | 148 | 180 | 7.0 | 28 | | | 6 -53½ | | |
| | 5 | | 146 | 179 | 7.5 | 31 | | | 5 -81 | | |
| 650° | 1 | 3 HRS. | 146 | 178 | 8.0 | 31 | | | 6 -56 | | |
| | 2 | | 147 | ~~159~~ | ~~3.0~~ | 31 | | | 5½-34½ | | DEFECT CHARPY DEFECT TENSILE |
| | 3 | | 146 | 177 | 8.0 | 31 | 30 | 5.7 | 5½-34 | 69.25 | DEFECT CHARPY |
| | 4 | | 145 | 176 | 7.5 | 28 | | | 5½-38½ | | DEFECT CHARPY |
| | 5 | | 145 | 178 | 8.0 | 39 | | | 6 -82½ | | |
| 650° | 1 | 4 HRS | 149 | 180 | 8.0 | 32 | | | 5½-65 | | |
| | 2 | | 147 | 179 | 7.5 | 31 | | | 4½-33 | | DEFECT CHARPY |
| | 3 | | 150 | 181 | 7.5 | 32 | 30.6 | 5.1 | 5½-72 | 70.53 | |
| | 4 | | 149 | 181 | 6.5 | 31 | | | 5½-28 | | DEFECT CHARPY |
| | 5 | | 145 | 179 | 9.0 | 27 | | | 4½-74 | | |

BAINITIC DUCTILE IRON PROJECT

| LOT No. | BAR No. | QCH TIME | YIELD ,000 | TENS. ,000 | ELONG. % | Rc Macro | Rc Micro | BHN | N-UNN CHARPY Ft Lb | LENGTH INCHES | COMMENT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 700° | 1 | 30min | 122 | 160 | 8.0 | 28 | | | 6-79 | | |
| | 2 | | 120 | 158 | 6.0 | 29 | | | 5¾ 68.5 | | |
| | 3 | | 121 | 159 | 8.5 | 23 | 27.4 | 6 | 5¾-81 | | |
| | 4 | | 119 | 159 | 7.5 | 28 | | | 6¼-33½ | | |
| | 5 | | 122 | 161 | 7.5 | 29 | | | 6¼-78½ | | |
| 700° | 1 | 1HR. | 124 | 162 | 11.5 | 29 | | | - 62 | | |
| | 2 | | 124 | 159 | 8.0 | 27 | | | 6½-35 | | DEFECT CHARPY |
| | 3 | | 125 | 162 | 9.5 | 27 | 28 | 6 | 6¼-61½ | | |
| | 4 | | 125 | 160 | 7.5 | 28 | | | 5-40½ | | DEFECT CHARPY |
| | 5 | | 123 | 162 | 9.5 | 29 | | | 6¼-93 | | |
| 700° | 1 | 2HRS | 130 | 162 | 9.5 | 29 | | | 6⅛-39½ | | DEFECT CHARPY |
| | 2 | | 129 | 160 | 9.5 | 31 | | | 5½-31 | | |
| | 3 | | 127 | 154 | 7.0 | 27 | 28.4 | 6.1 | 5½-19½ | | DEFECT CHARPY |
| | 4 | | 128 | 162 | 9.5 | 27 | | | 6½-30½ | | DEFECT CHARPY |
| | 5 | | 126 | 156 | 8.0 | 28 | | | 6½-51½ | | |
| 700° | 1 | 3HRS | 123 | 158 | 8.5 | 26 | | | 5¾-109 | | |
| | 2 | | 128 | 161 | 9.5 | 28 | | | 6-17 | | DEFECT CHARPY |
| | 3 | | 128 | 160 | 9.0 | 26 | 27.6 | 6.4 | 6½-95 | | |
| | 4 | | 127 | 161 | 9.5 | 30 | | | 6¼-32 | | |
| | 5 | | 125 | 163 | 10.5 | 28 | | | 6½-97 | | |
| 700° | 1 | 4HRS | 130 | 162 | 9.0 | 29 | | | 6¼-103 | | |
| | 2 | | 130 | 161 | 9.0 | 28 | | | 6-71½ | | |
| | 3 | | 129 | 161 | 10.0 | 30 | 27.2 | 6.05 | 6-78½ | | |
| | 4 | | 128 | 159 | 9.0 | 26 | | | 6-78½ | | |
| | 5 | | 128 | 159 | 8.5 | 28 | | | 6-111 | | |

BAINITIC DUCTILE IRON PROJECT

| LOT No. | BAR No. | QCH TIME | YIELD ,000 | TENS. ,000 | ELONG. % | Rc Macro | Rc Micro | BHN | N-UNN CHARPY Ft Lb | LENGTH INCHES | COMMENT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 750° | 1 | 30MIN | 104 | 137 | 7.0 | 25 | | | 8 - 59 | | |
| | 2 | | 104 | 137 | 7.0 | 25 | | | 7½ - 88½ | | |
| | 3 | 103.8 | 102 | 138.8 138 | 8.4 8.5 | 25 25.2 | | 7.6 | 7½ - 54½ | 67.375 | |
| | 4 | | 102 | 140 | 10.0 | 26 | 34.2 | | 7½ 38 | | DEFECT CHARPY |
| | 5 | | 106 | 142 | 9.0 84 | 25 ± .805 | | | 7½ - 67½ | | |
| 750° | 1 | 1 HR. | 107 | 138 | 7.0 | 25 | | | 7 41½ | | DEFECT CHARPY |
| | 2 | | 105 | 138 | 8.0 | 24 | | | 6½ - 43½ | | |
| | 3 | 105.6 | 107 | 139.2 141 | 8.5 9.5 | 25 25.2 | | 6.9 | 6¾ - 79 | 79.3 | |
| | 4 | | 106 | 140 | 9.5 | 24 | | | 7½ - 86 | | |
| | 5 | | 103 | 139 | 8.5 | 26 | | | 6¾ - 103 | | |
| 750° | 1 | 2 HRS. | 105 | 143 | 8.0 | 25½ | | | 5¼ 30½ | | DEFECT CHARPY |
| | 2 | | 108 | 144 | 7.0 | 25 25.5 | | 4.75 | 4½ - 47 | 65.75 | |
| | 3 | 108.8 | 108 | 142 144 | 6.6 7.0 | 25 | | | 4¾ - 84 | | |
| | 4 | | 108 | 143 | 6.0 | 26 | | | 5 - 24½ | | DEFECT CHARPY |
| | 5 | | 115 | 138 | 5.0 | 26 | | | 4¼ - 60½ | | |
| 750° | 1 | 3 HRS | 109 | 146 | 5.5 | 26 | | | 3¼ - 34 | | |
| | 2 | | 109 | 145 | 5.5 | 25 | | 3.15 | 3 11 | | DEFECT CHARPY |
| | 3 | 109.8 | 111 | 146.6 148 | 5.4 5.0 | 26 25.2 | | | 2¾ 36 | 36 | DEFECT CHARPY |
| | 4 | | 109 | 143 | 5.0 | 24 | | | 2¾ 12 | | DEFECT CHARPY |
| | 5 | | 111 | 151 | 6.0 | 24 | | | 4 45½ | | DEFECT CHARPY |
| 750° | 1 | 4 HRS | 112 | 146 | 4.0 | 25 | | | 2 10 | | DEFECT CHARPY |
| | 2 | | 113 | 151 | 4.5 | 24¼ | | 2.65 | 2¾ 6 | | DEFECT CHARPY |
| | 3 | 113.2 | 114 | 148.2 148 | 3.9 3.0 | 24 24.4 | | | 3 - 28 | 30 | |
| | 4 | | 114 | 144 | 3.5 | 24 | | | 2¼ 9 | | DEFECT CHARPY |
| | 5 | | 113 | 150 | 4.5 | 25 | | | 2¼ - 32 | | |

SUSPECT 750° SALT

BAINITIC DUCTILE IRON PROJECT

| LOT No. | BAR No. | QCH TIME | YIELD ,000 | TENS. ,000 | ELONG. % | Rc Macro | Rc Micro | BHN | N- UN CHARPY Ft Lb | LENGTH INCHES | COMMENT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 800° | 1 | 30 MIN | 76 | 125 | 8.0 | 22 | | | 6- — | | |
| | 2 | | 77 | 125.8 125 | 8.4 7.5 | 22 | | | 5-120+ | | |
| | 3 | | 76.4 77 | 128 | 10.0 | 25 | 24 | 5.25 | 5¼-113 | 120 + | |
| | 4 | | 76 | 125 | 7.5 | 26 | | | 5¼-77 | | |
| | 5 | | 76 | 126 | 9.0 | 25 | | | 4¾-120+ | | |
| 800° | 1 | 1 HR. | 102 | 137 | 5.0 | 24 | | | 2½ 11 | | DEFECT. CHARPY |
| | 2 | | 102 | 140 | 4.8 5.0 | 25 | 24.6 | 2.2 | 2- 1½ | | DEFECT. CHARPY |
| | 3 | | 102 105 | 137.6 140 | 4.5 | 24 | | | 2¼-39 | | |
| | 4 | | 100 | 135 | 4.5 | 25 | | | 2¼-45 | 42 | |
| | 5 | | 101 | 134 | 5.0 | 25 | | | 2- 26 | | |
| 800° | 1 | 2 HRS. | 101 | 137 | 4.0 | 23 | | | 2 20 | | DEFECT CHARPY |
| | 2 | | 101 | 141 | 5.0 | 25 | | | 1¾-38 | | |
| | 3 | 102.4 | 101 | 137.6 136 | 4.6 4.5 | 22 | 23.6 | 1.8 | 1¾- 32 | 28.3 | |
| | 4 | | 104 | 139 | 5.0 | 24 | | | 1¾-20 | | |
| | 5 | | 105 | 135 | 4.5 | 24 | | | 1¾- 31½ | | |
| 800° | 1 | 3 HRS | 100 | 135 | 4.5 | 23 | | | 1½ 33½ | | DEFECT CHARPY |
| | 2 | | 100 | 135 | 5.0 | 23 | | | 2- 29 | | |
| | 3 | 101 | 100 | 135.6 135 | 4.5 4.5 | 22 | 22.8 | N | 2- 34½ | 33.8 | |
| | 4 | | 105 | 140 | 4.5 | 23 | | | 2- 37 | | |
| | 5 | | 102 | 133 | 4.0 | 23 | | | 2- 35 | | |
| 800° | 1 | 4 HRS. | 101 | 131 | 3.5 | 22 | | | 2- 4 | | DEFECT CHARPY |
| | 2 | | 104 | 140 | 5.0 | 23 | | | 2¼-26½ | | |
| | 3 | 102 | 104 | 134.8 135 | 3.8 4.0 | 23 | 22.4 | N | 2- 36 | 30.25 | |
| | 4 | | 100 | 135 | 3.0 | 21 | | | 2- 28 | | |
| | 5 | | 103 | 133 | 3.5 | 23 | | | 2- 30½ | | |

152
72
224

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# APPENDIX C

# PHOTOMICROGRAPHS OF STRUCTURES RESULTING FROM VARIOUS HEAT-TREATMENTS

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BDI Quenched at $400^oF$. The sharp needle-like structure indicates a high proportion of martensite accounting for the high hardness and low UTS. X 800

BDI Quenched at $500^oF$. Here the sharpness of the needles is replaced with the feathery structure of bainite. The UTS increases and the hardness decreases. X 800

BDI Quenched at $600^oF$. The feathery structure of bainite has increased to where it almost entirely fills the matrix. This is characteristic of good quality BDI. X 800

BDI Quenched at 700°F. The light areas are retained austenite which contributes to the lower hardness and greater toughness of this structure. X 800.

BDI Quenched at 800°F. The retained austenite has become more pronounced also some areas of pearlite. The structure is, in fact, getting back to a pearlitic nodular iron of very fine structure and has the physical properties to go with it. X 800

# APPENDIX D

# TEMPERATURE CHARACTERIZATION

# OF BDI

# FROM -60° to 230°F

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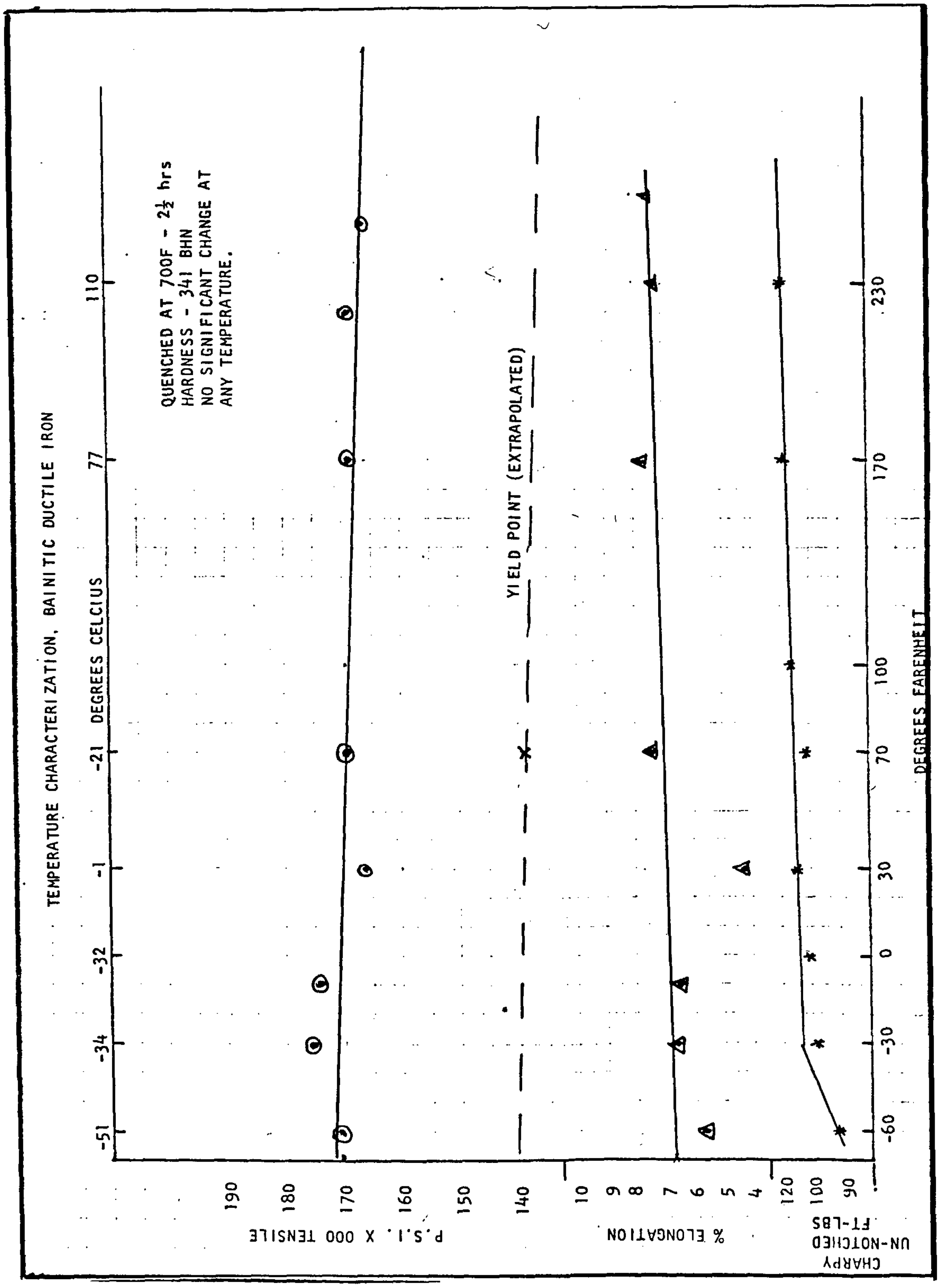
TEMPERATURE CHARACTERIZATION, BAINITIC DUCTILE IRON
DEGREES CELCIUS
-51 -34 -32 -1 -21 77 110
QUENCHED AT 700F - 2½ hrs
HARDNESS - 341 BHN
NO SIGNIFICANT CHANGE AT
ANY TEMPERATURE.
YIELD POINT (EXTRAPOLATED)
P.S.I. X 000 TENSILE
190 180 170 160 150 140
% ELONGATION
10 9 8 7 6 5 4
CHARPY
UN-NOTCHED
FT-LBS
120 100 90
-60 -30 0 30 70 100 170 230
DEGREES FARENHEIT

TEMPERATURE CHARACHERIZATION

BAINITIC DUCTILE IRON PROJECT

| LOT No. | BAR No. | HRS QCH TIME | YIELD ,000 | TENS. ,000 | ELONG. % | Rc Macro | Rc Micro | BHN | CHARPY Ft Lb | LENGTH INCHES | COMMENT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 2.5 | 137.5 | 164.7 | 4.5 | | | | 117.5 | | PULLED w/o JACKET |
| | 2 | | | 172.2 | 7.0 | | | | 94 | | |
| -60°F | 3 | | | 171.7 | 5.0 | 5.9 | | | 87 | 93.7 | |
| | 4 | | | 169.3 | 5.5 | | | | 84 | | |
| | 5 | | | 174.2 | 7.5 | | | | 86 | | |
| | | | AVE | 170.4 | | | | | | | |
| 2 | 1 | | | 180.8 | 10.0 | | | | ~~25~~ | | |
| | 2 | | | 173.7 | 7.5 | | | | 47 | | |
| -31°F | 3 | | | 177.0 | 7.5 | | | | 120+ | | UN BROKEN |
| | 4 | | | 179.3 | 4.5 | | | | 84.5 | | |
| | 5 | | | 166.7 | 5.0 | | | | 53 | | |
| | | | AVE | 175.5 | 6.9 | | | | 76 | | |
| 3 | 1 | | | 172.6 | 5.5 | | | | 66 | | |
| | 2 | | | 177.2 | 7.0 | | | | ~~34~~ | | |
| | 3 | | | 171.4 | 5.5 | | | | 120+ | | UNBROKEN |
| -10°F | 4 | | | 177.0 | 9.0 | | | | 120+ | | " |
| | 5 | | | 174.2 | 5.5 | | | | 62.5 | | |
| | | | AVE | 174.5 | 6.5 | | | | 92 | | |
| 4 | 1 | | | 157.6 | 5.5 | | | | 120 | | |
| | 2 | | | 160.2 | 3.5 | | | | 80 | | |
| | 3 | | | 167.8 | 5.5 | | | | 120+ | | UNBROKEN |
| 35°F | 4 | | | 165.0 | 5.0 | | | | ~~46~~ | | |
| | 5 | | | 164.0 | 4.0 | | | | 120 | | |
| | | | AVE | 162.9 | 4.7 | | | | 110 | | |
| 5 | 1 | | 139.3 | 170.6 | 7.5 | | | | ~~28~~ | | |
| | 2 | | 140.0 | 168.8 | 7.0 | | | | 120+ | | UN BROKEN |
| | 3 | | 136.8 | 169.4 | 7.0 | | | | 65 | | |
| 72°F | 4 | | 141.8 | 172.1 | 9.0 | | | | 60 | | |
| | 5 | | 138.2 | 164.6 | 6.0 | | | | 54 | | |
| | | AVE | 139.2 | 169.1 | 7.5 | | | | 74.75 | | |
| 6 | 1 | | | | | | | | | | |
| | 2 | | | | | | | | | | |
| | 3 | | | | | | | | | | |
| | 4 | | | | | | | | | | |
| | 5 | | | | | | | | | | |

## TEMPERATURE CHARACTERIZATION

BAINITIC DUCTILE IRON PROJECT

| LOT No. | BAR No. | HRS QCH TIME | YIELD ,000 | TENS. ,000 | ELONG. % | Rc Macro | Rc Micro | BHN | CHARPY Ft Lb | LENGTH INCHES | COMMENT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 1 | 2.5 | | 167.7 | 8.0 | | | | 95 | | |
| | 2 | | | 167.7 | 7.5 | | | | ~~57~~ | | |
| 170°F | 3 | | | 166.3 | 8.5 | | | | 105 | | |
| | 4 | | | 164.3 | 8.0 | | | | 120+ | | UNBROKEN |
| | 5 | | | 169.5 | 7.0 | | | | 70 | | |
| | | | AVE. | 167.1 | 7.8 | | | | 97.5 | | |
| | | | | | | | | | | | |
| 7 | 1 | | | 168.7 | 6.0 | | | | 75 | | |
| | 2 | | | 168.0 | 7.5 | | | | 101 | | |
| 230°F | 3 | | | 168.5 | 7.5 | | | | 110 | | |
| | 4 | | | 166.5 | 7.0 | | | | 80 | | |
| | 5 | | | 165.2 | 7.5 | | | | ~~57~~ | | |
| | | | AVE | 167.38 | 7.1 | | | | 91.5 | | |

NOTE: CHARPY MACHINE LIMIT IS 120 FT lbs.

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# APPENDIX E

## EFFECT OF HIGH MOLYBDENUM

## &

## RE-HEAT-TREATMENT ON MECHANICAL PROPERTIES

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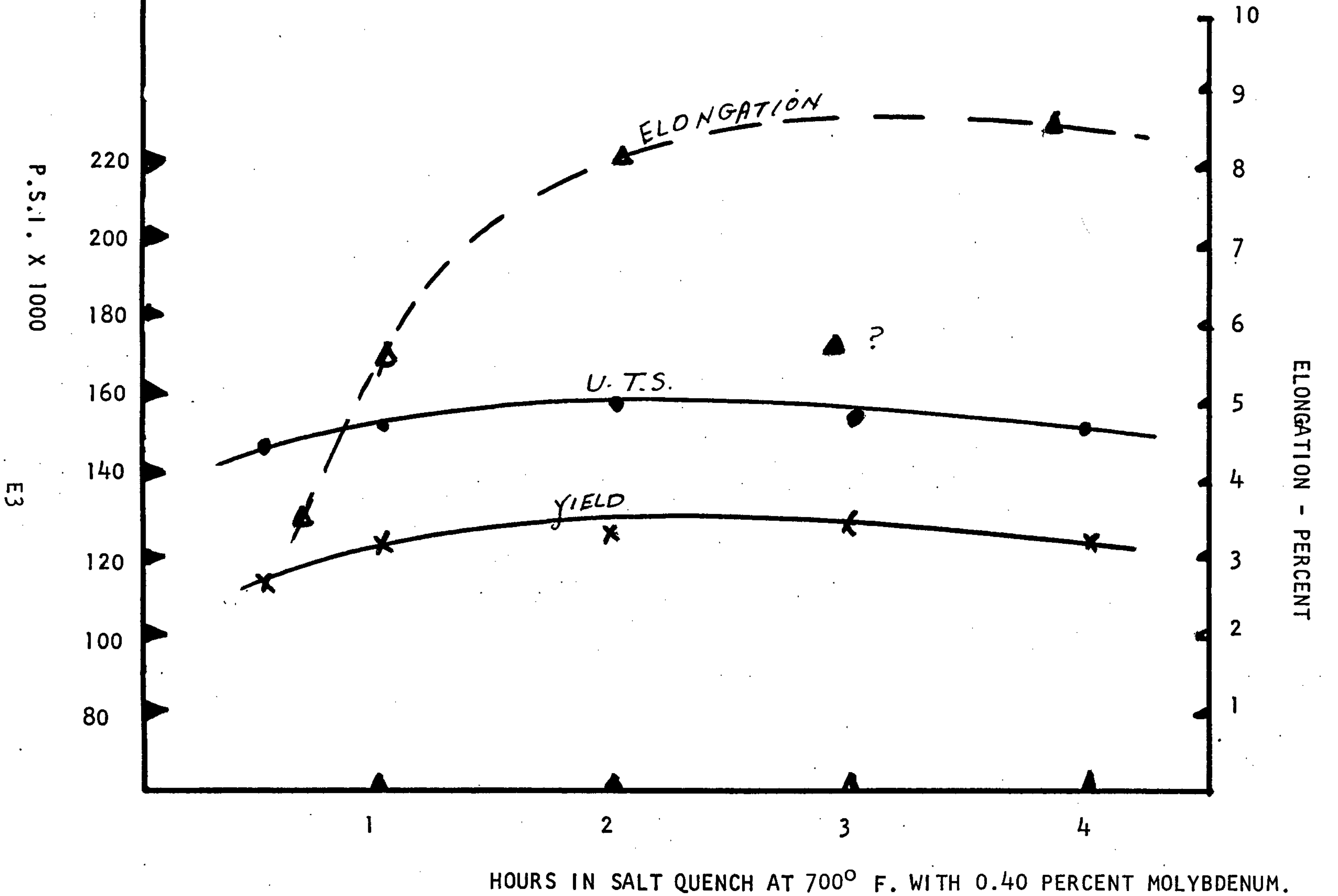
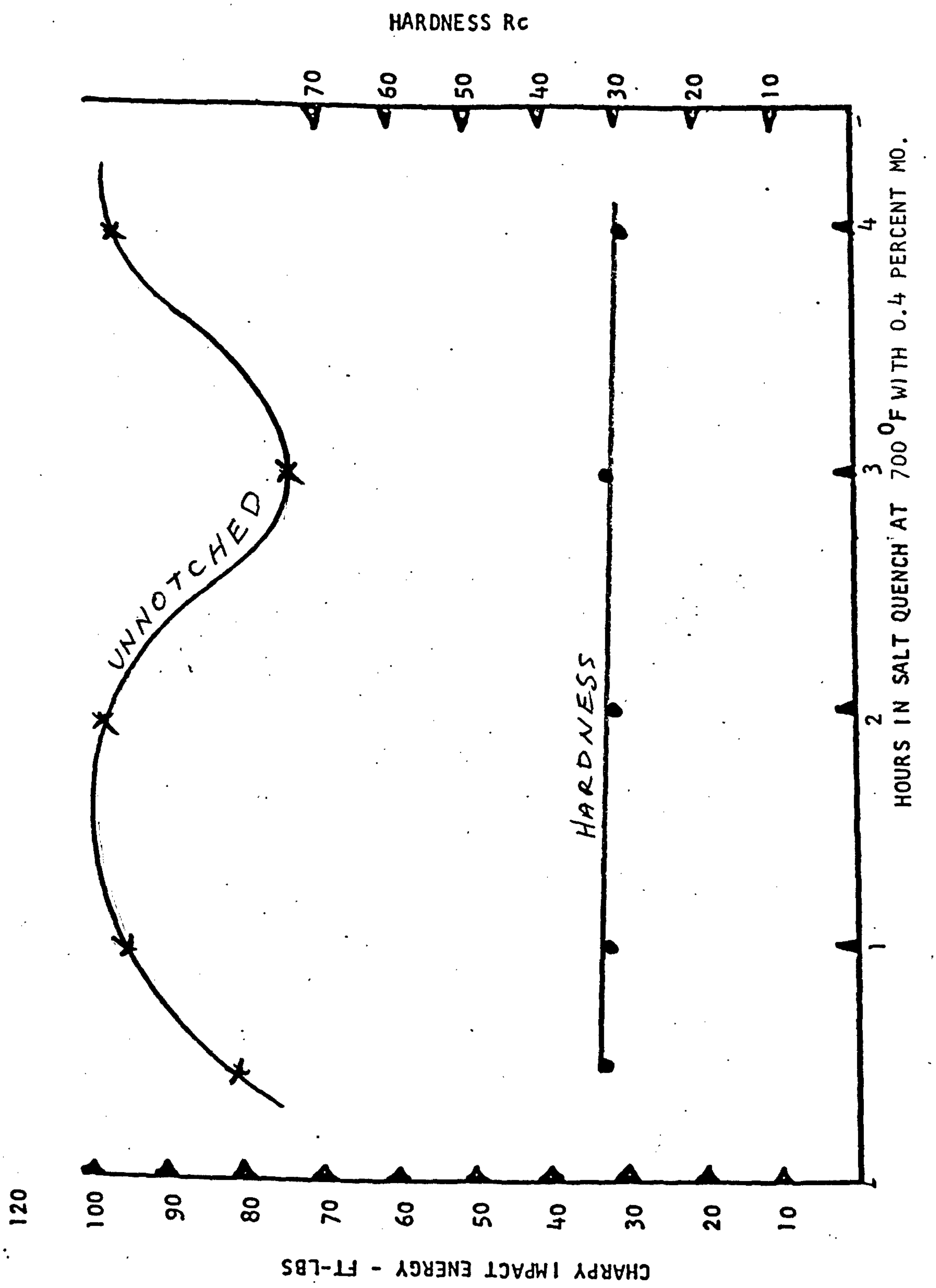
EFFECT OF TIME IN QUENCH ON TENSILE, YIELD AND ELONGATION



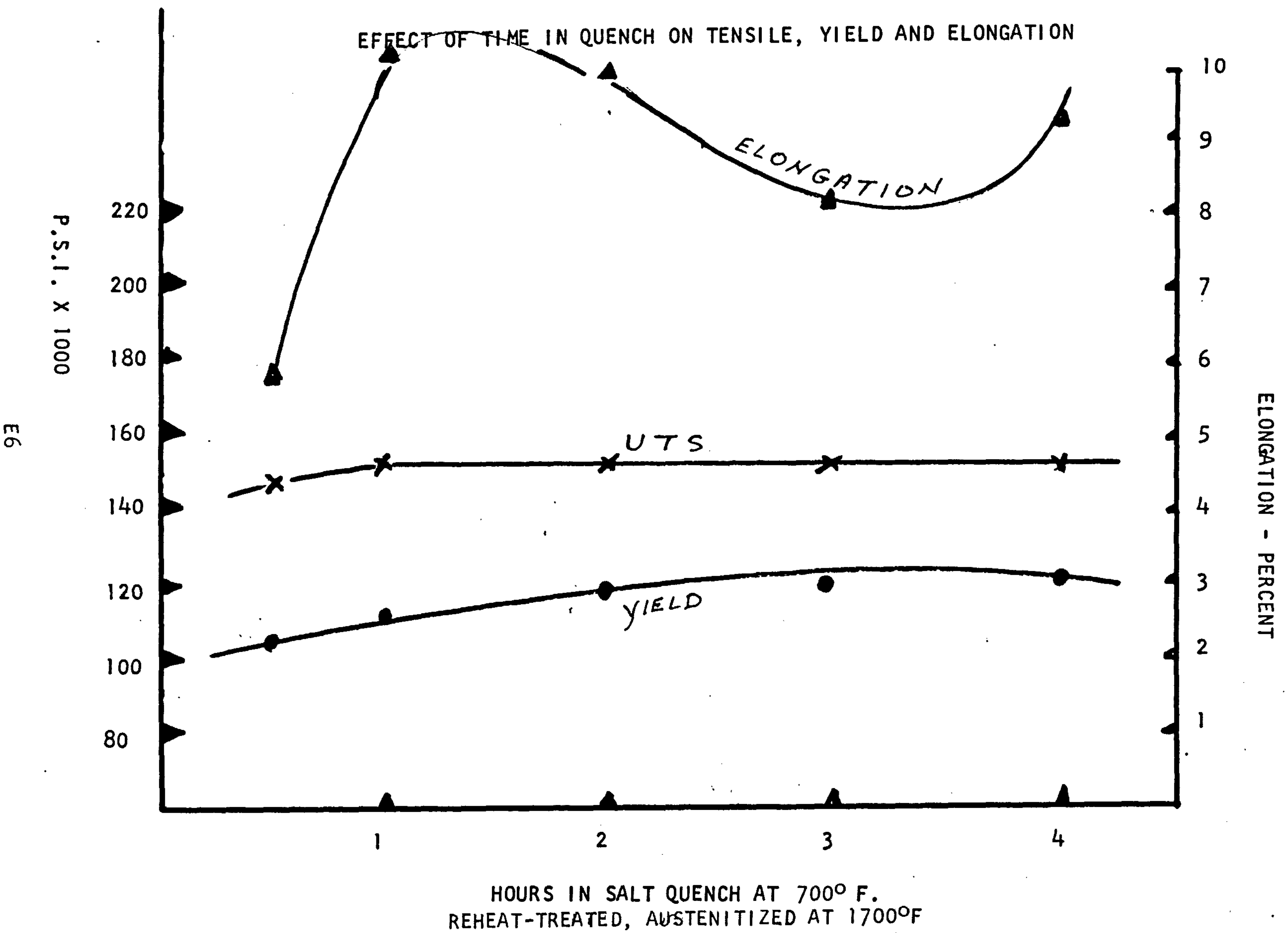
NOTE: Hardness shown is apparent or macro hardness. Actual hardness as measured by Brinnell hardness tester will measure 5 to 7 points harder.




EFFECT OF TIME IN QUENCH ON CHARPY IMPACT - NOTCHED AND UNNOTCHED AND HARDNESS

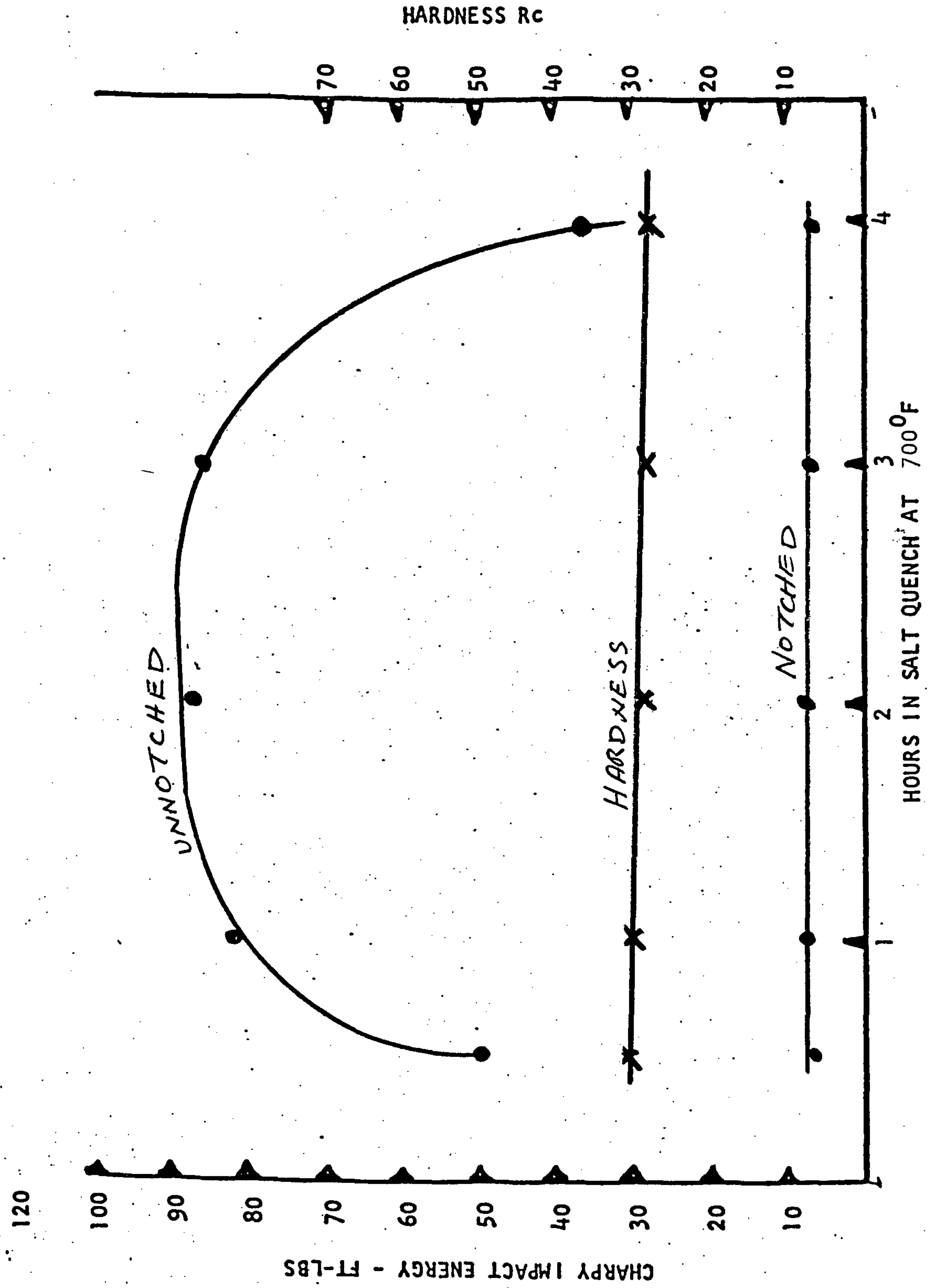
BAINITIC DUCTILE IRON PROJECT

| LOT No. | BAR No. | QCH TIME | YIELD ,000 | TENS. ,000 | ELONG. % | Rc Macro | Rc Micro | BHN | UNNOTCHED CHARPY Ft Lb | LENGTH INCHES | COMMENT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 700° | 1-2 | 30MIN | 117 | 149 | 3.5 | 34 | | | 62-78 | | |
| .4% FeMo | 3-4 | | | | | | | | 17-31 | | DEFECT CHARPY |
| | 5-6 | | | | | | | | 76-34½ | | DEFECT CHARPY |
| | 7-8 | | | | | | | | 43-69½ | | DEFECT CHARPY |
| | 9-10 | | | | | | | | 95-107½ | | |
| | | | | | | | | | 81 | | |
| 700° | 1-2 | 1HR. | 124 | 154 | 5.5 | 33 | | | 120+-108 | | |
| .4% FeMo | 3-4 | | | | | | | | 40-66 | | DEFECT CHARPY |
| | 5-6 | | | | | | | | 30-41½ | | DEFECT CHARPY |
| | 7-8 | | | | | | | | 43-71 | | DEFECT CHARPY |
| | 9-10 | | | | | | | | 113¼-96 | | |
| | | | | | | | | | 95 | | |
| 700° | 1-2 | 3HRS. | 126 | 158 | 8.0 | 32 | | | 28½-103 | | DEFECT CHARPY |
| .4% FeMo | 3-4 | | | | | | | | 61½-101 | | |
| | 5-6 | | | | | | | | 26-23 | | DEFECT CHARPY |
| | 7-8 | | | | | | | | 48-29 | | DEFECT CHARPY |
| | 9-10 | | | | | | | | 120+99 | | |
| | | | | | | | | | 97 | | |
| 700° | 1-2 | 3HRS | 128 | 154 | 5.5 | 33 | | | 89-20 | | DEFECT CHARPY |
| .4% FeMo | 3-4 | | | | | | | | 69-65 | | |
| | 5-6 | | | | | | | | 92-58 | | |
| | 7-8 | | | | | | | | 44-41 | | DEFECT CHARPY |
| | 9-10 | | | | | | | | 68-75 | | |
| | | | | | | | | | 74 | | |
| 700° | 1-2 | 4HRS | 123 | 152 | 8.5 | 31 | | | 38-33 | | DEFECT CHARPY |
| .4% FeMo | 3-4 | | | | | | | | 73-110 | | |
| | 5-6 | | | | | | | | 98-85 | | |
| | 7-8 | | | | | | | | 98-34 | | DEFECT CHARPY |
| | 9-10 | | | | | | | | 120+-87 | | |
| | | | | | | | | | 96 | | |



EFFECT OF TIME IN QUENCH ON TENSILE, YIELD AND ELONGATION
P.S.I. X 1000
220
200
180
160
140
120
100
80
ELONGATION - PERCENT
10
9
8
7
6
5
4
3
2
1
ELONGATION
UTS
YIELD
1
2
3
4
HOURS IN SALT QUENCH AT 700° F.
REHEAT-TREATED, AUSTENITIZED AT 1700°F

NOTE: Hardness shown is apparent or macro hardness. Actual hardness as measured by Brinnell hardness tester will measure 5 to 7 points harder.




EFFECT OF TIME IN QUENCH ON CHARPY IMPACT - NOTCHED AND UNNOTCHED AND HARDNESS

REHEAT-TREATED, AUSTENITIZED AT 1700$^{\circ}$F

## BAINITIC DUCTILE I PROJECT

| LOT No. | BAR No. | QCH TIME | YIELD ,000 | TENS. ,000 | ELONG. % | Rc Macro | Rc Micro | BHN | N-UA CHARPY Ft Lb | LENGTH INCHES | COMMENT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1700° | 1 | 30 MIN | 108 | 153 | 5.5 | 29 | | | 6½-58½ | | |
| 700° | 2 | | 112 | 153 | 7.5 | 30 | | | 6¼-37 | | |
| REDO | 3 | | 106 | 147 | 5.5 | 30 | | | 6½-41 | | |
| | 4 | | — | 146 | 6.0 | 29 | | | 6-57 | | |
| | 5 | | 112 | 147 | 5.0 | 31 | | | 6¼ 20 | | DEFECT CHARPY |
| | | | 109 | 149.2 | 5.9 | 29.8 | | | 6.37 | 48.3 | |
| 700° | 1 | 1 HR. | 114 | 155 | 10.0 | 29 | | | 7-50 | | DEFECT CHARPY |
| REDO | 2 | | 115 | 150 | 10.0 | 28 | | | 6¾-83 | | |
| | 3 | | 113 | 153 | 9.5 | 29 | | | 6¾-95 | | |
| | 4 | | 110 | 151 | 9.5 | 30 | | | 7¼ 33 | | DEFECT CHARPY |
| | 5 | | 110 | 156 | 10.5 | 29 | | | 6¾-67 | | |
| | | | 112 | 153 | 9.9 | 29 | | | 6.8 | 81.6 | |
| 700° | 1 | 2 HRS | 121 | 152 | 8.5 | 29 | | | 6½ 14½ | | DEFECT CHARPY |
| REDO | 2 | | 117 | 153 | 10.5 | 29 | | | 7-92 | | |
| | 3 | | 122 | 153 | 10.0 | 29 | | | 7¾-73½ | | |
| | 4 | | 118 | 153 | 9.0 | 28 | | | 6½-94 | | |
| | 5 | | 121 | 157 | 9.5 | 30 | | | 7½-87½ | | |
| | | | 120 | 153.6 | 9.5 | 29 | | | 7.05 | 86.75 | |
| 700° | 1 | 3 HRS | 122 | 152 | 7.5 | 30 | | | 7-16 | | DEFECT CHARPY |
| REDO | 2 | | 125 | 155 | 7.5 | 28 | | | 6½ 43 | | DEFECT CHARPY |
| | 3 | | 121 | 156 | 8.0 | 27 | | | 6¾ 25 | | DEFECT CHARPY |
| | 4 | | 118 | 153 | 9.5 | 29 | | | 6¼-99 | | DEFECT CHARPY |
| | 5 | | 121 | 151 | 8.5 | 29 | | | 6¾-73 | | |
| | | | 121 | 153 | 8.2 | 28.6 | | | 6.65 | 86 | |
| 700° | 1 | 4 HRS | 122 | 153 | 10.5 | 28 | | | 6¾ 38½ | | |
| REDO | 2 | | 123 | 153 | 9.0 | 28 | | | 5½ — | | |
| | 3 | | 124 | 155 | 9.0 | 29 | | | 7-~~102½~~ | | |
| | 4 | | 120 | 155 | 9.0 | 29 | | | 7 34 | | DEFECT CHARPY |
| | 5 | | 122 | 157 | 9.5 | 27 | | | 7 41 | 37.8 | |
| | | | 122 | 154 | 9.4 | 28.2 | | | 6.85 | | |

APPENDIX F

FIRST STATIC EXPERIMENTAL

STRESS ANALYSIS

STRAIN GAGE POSITIONS AND DATA

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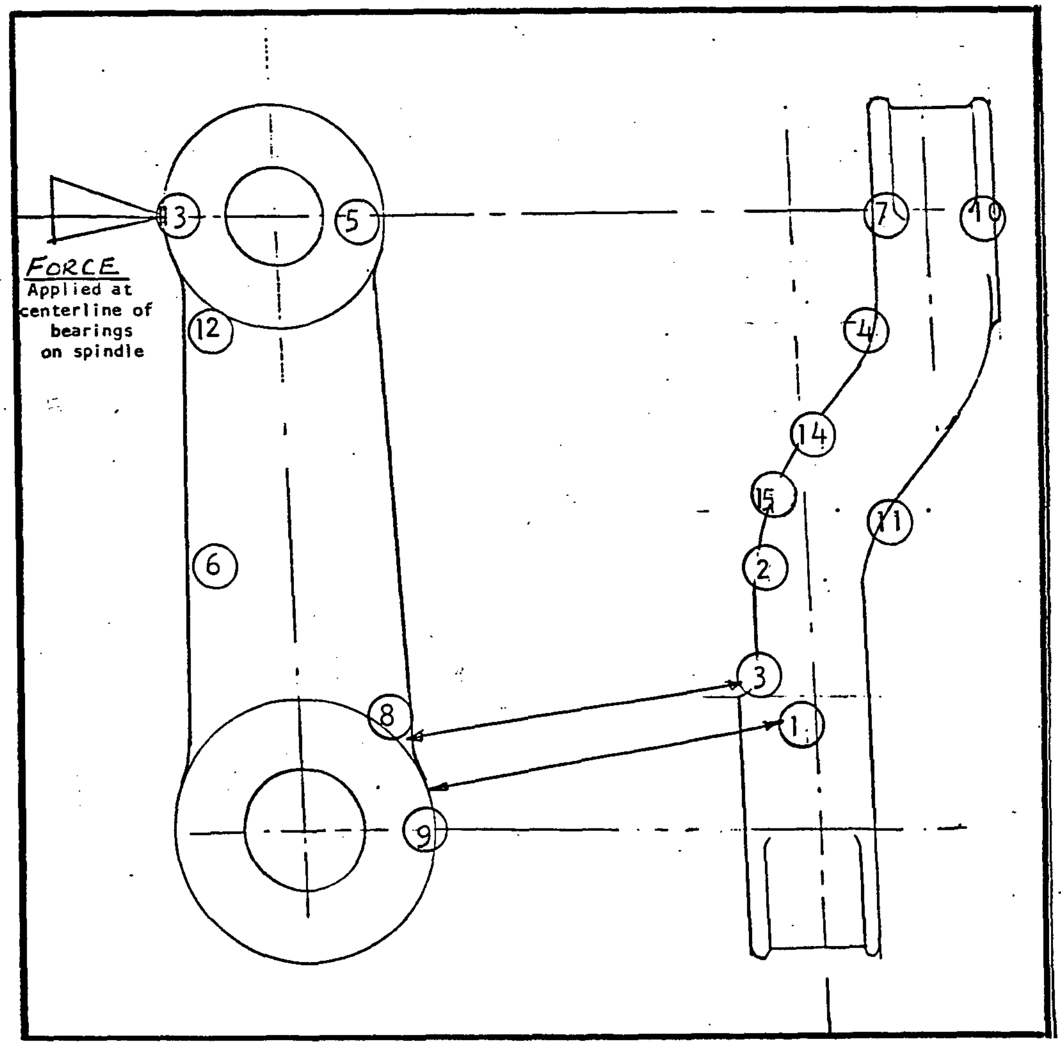


STRAIN u IN/IN

| Load | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5000 | 384 | 176 | 389 | 259 | -3 | 226 | 21 | -174 | 18 | 20 | -435 | -214 | 0 | -113 | -80 |
| 10,000 | 701 | 361 | 790 | 521 | -9 | 445 | 66 | -333 | 82 | 46 | -874 | -445 | -9 | -224 | -157 |
| 15,000 | 1000 | 544 | 1184 | 779 | -10 | 667 | 108 | -483 | 158 | 123 | -1311 | -680 | -8 | -333 | -232 |
| 20,000 | 1297 | 716 | 1555 | 1039 | -10 | 892 | 153 | -602 | 227 | 218 | -1750 | -912 | -3 | -439 | -304 |

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